6-2012

# Transnational Intellectual Property Strategies and Firms' Knowledge Adoption: Evidence from China-U.S. Patent Dyads

Kenneth Guang-Lih HUANG
*Singapore Management University*, kennethhuang@smu.edu.sg

Jiatao Li

Paper to be presented at the DRUID 2012

on

June 19 to June 21

at

CBS, Copenhagen, Denmark,

# Transnational Intellectual Property Strategies and Firms' Knowledge Adoption: Evidence from China-U.S. Patent Dyads

**Kenneth G. Huang**
Singapore Management University
Lee Kong Chian School of Business
kennethhuang@smu.edu.sg

**Jiatao (J.T.) Li**
Hong Kong University of Science and Technology
School of Business and Management
mnjtli@ust.hk

Abstract

As firms increasingly operate and conduct R&D in emerging markets, 'transnational patenting' - patenting of the same invention across more than one country - is becoming a cornerstone of their intellectual property (IP) strategies. We investigate whether and how a patent granted to a focal firm's invention in an emerging economy (China) can shape its subsequent technological knowledge adoption by other firms in developed economies (U.S.). Drawing on research from market signaling and intellectual property strategy, we address this question using a novel dataset of 4,226 China-U.S. patent dyads covering 1,104 firms, and matching control sets. Difference-in-differences estimates show that patent granted to the focal firm's invention under a weak IP institution (China) increases its subsequent knowledge adoption (by up to 76%) by other firms under a strong IP institution (U.S.). The signaling effect to mitigate information asymmetry is most salient for patents awarded to China-based firms, in computing and information sector, and to technologies developed in Chinese provinces with lower de facto IP institutional quality.

Jelcodes:O34,O32

# Transnational Intellectual Property Strategies and Firms' Knowledge Adoption: Evidence from China-U.S. Patent Dyads

**Kenneth G. Huang**
Assistant Professor of Strategic Management
Lee Kong Chian School of Business
Singapore Management University
50 Stamford Road #05-01
Singapore, 178899
Tel: +(65) 6828-0525
E-mail: kennethhuang@smu.edu.sg

**Jiatao (J.T.) Li**
Chair Professor of Management
School of Business and Management
Hong Kong University of Science and Technology
Clear Water Bay
Kowloon, Hong Kong

April 29, 2012

We thank Wenxin Guo and Clint Gono for their excellent research assistance.
All errors are our own.

# Transnational Intellectual Property Strategies and Firms' Knowledge Adoption: Evidence from China-U.S. Patent Dyads


## ABSTRACT

As firms increasingly conduct R&D in emerging markets, 'transnational patenting'– patenting of the same invention across more than one country– is becoming a cornerstone of their intellectual property (IP) strategies. We investigate how patenting of a firm's invention in an emerging economy (China) can shape its subsequent technological knowledge adoption by other firms in a developed economy (U.S.). Using 4,226 China-U.S. patent dyads covering 1,104 firms, our difference-in-differences estimates show that patent grant under a weak IP institution (China) increases the technology's knowledge adoption under a strong IP institution (U.S.). Such signaling effect to mitigate information asymmetry is most salient for patents awarded to China-based firms, in computing and information sector, and to technologies developed in Chinese provinces with lower *de facto* IP institutional quality.



**Keywords:** Innovation, transnational patenting, technological knowledge, emerging market, China

## INTRODUCTION

As more firms and organizations operate and conduct R&D in emerging markets, ‘transnational patenting’ – patenting of the same invention across more than one country – is becoming a critical part of their intellectual property (IP) strategies. Transnational patenting of the same invention often occurs first in a country where R&D is conducted and subsequently in another country of high market potential. Increasingly, the locus of R&D and innovative activities has been shifting to the emerging economies such as China as domestic start-ups, innovative firms, and multinational corporations (MNCs) develop novel technologies and product platforms there to take advantage of the availability of low cost technical personnel and proximity to market (Barrett, van Biljon, and Musso, 2011; Zhao, 2006). These firms and organizations often apply for patents first to protect their inventions developed there before doing the same in another major market such as the U.S.

From 1995 to 2004, the number of U.S. patents awarded to U.S. firms based on technologies first developed outside the U.S. in non-OECD countries has more than doubled (OECD, 2005). Furthermore, the number of patents in the major science and technology classes awarded by the State Intellectual Property Office (SIPO) of the People's Republic of China to U.S. firms and organizations conducting R&D in China has increased 468 times over a 20 year period from only 5 in 1986 to 2,338 in 2006 (SIPO, 2008). At the same time, anecdotal evidence suggests that firms in the U.S. are placing ‘…increased emphasis on clearance searching and monitoring, especially before a new product is launched in China’ (Lin, 2011) as part of their transnational patenting strategies. Our own conversations with R&D managers of MNCs and domestic Chinese firms, their in-house patent lawyers and other patent attorneys based in China specializing in procurement, management and enforcement of SIPO patents also indicate that firms in the U.S. increasingly commission extensive ‘prior art studies’ of SIPO patents issued to firms operating in China (in addition to U.S. and European patents) either before filing for a patent application or developing a new product to help them plan for their own technology development and patent portfolios.[1]

[1] Several face-to-face semi-structured interviews and phone interviews with managers of U.S. and other foreign

Patents fulfill Spence's (1973) original conceptualization of a signal: there is substantial cost involved in securing them through a lengthy application and grant process; and thus they provide a mechanism by which the quality of an innovation can be sorted. While some scholars argued that patenting is too 'noisy' a signal to influence the expectation of public investors proxied by the amount of funds raised in initial public offerings (IPOs) (Deeds, Decarolis, and Coombs, 1997), others found a significant relationship between patent filing, grant and investment. For example, Stuart, Hoang, and Hybels (1999) find that biotechnology start-ups advertise their patent applications and awards prominently when filing for IPOs. Furthermore, those start-ups with more patents go to IPO faster and are worth more when they do. Using evidence from IPO offerings, Heeley, Matusik, and Jain (2007) find that patents serve an economically meaningful role as signaling devices to public equity investors in biopharmaceutical and chemical sectors but not in information technology related sectors.

Other evidence suggests that patenting activities enable new ventures to secure funding on more favorable terms or help them garner preferential access to the 'extra-financial services' of prominent venture capital investors (Hsu, 2004). In a more recent study, Hsu and Ziedonis (2008) find that patents serve as signals to significantly increase investors' estimates of start-up valuations (by more than 28%); with the effect more pronounced in earlier financing rounds and when the funds are secured from more prominent investors.

While these studies support the notion that patents can serve as signals for innovating firms to gain financing, resources and reputation, we still lack the conceptual framework and empirical evidence on whether and how transnational patents, by acting as a signal in one market, can influence technological knowledge processes in another. Specifically, to what extent can the patent awarded to a focal firm in an emerging economy with a weak IP regime (e.g., China) shape the technology's adoption by other firms in developed economies with strong IP regimes (e.g., the U.S.)? What are the moderating roles of organizational home base, technology sector, and R&D location in regions of lower *de facto* IP institutional quality

based MNCs conducting R&D in China and domestic Chinese firms, their in-house patent lawyers, patent attorneys in specialized IP law firms and service providers, and SIPO officials were conducted between March 2008 to April 2012 in the U.S., Beijing, Shanghai and Singapore. Information was updated through e-mails and phone calls in the following months on confidentiality conditions.

(such as those Chinese provinces with less robust IP system and greater IP uncertainty) in this relationship? These questions have important implications considering the increasingly prominent roles of R&D by firms in emerging economies with weak or ineffectual IP regime.

This study seeks to address these pertinent questions and make the following contributions. First, it contributes to the body of research on the strategic and economic value of intellectual property right (IPR) to innovating firms (Gans, Hsu, and Stern, 2008; Heeley *et al.*, 2007; Hsu and Ziedonis, 2008; Stuart *et al.*, 1999). Empirical evidence on the impact of firm patenting – particularly patenting strategies in the emerging countries – on other firms' knowledge processes is limited and inconclusive. Much prior literature has focused on how patenting shapes knowledge production and accumulation in the public domain in developed countries (Murray and Stern, 2007; Sorenson and Fleming, 2004). This study sheds light on the role of transnational patents as signals to mitigate information asymmetry between focal firms developing a novel technology in an emerging economy and other firms observing such development in a more developed economy. Furthermore, it contributes new insights into the causal linkage between the conferring of a patent right to the focal firm (under the weak IPR institution of China) and the strategic responses by other firms in their subsequent technological knowledge activities (under the strong IPR institution of the U.S.). We find that transnational patents obtained by innovating firms in the emerging economy can influence knowledge adoption by other firms in the developed economies.

Second, this study advances our understanding of the microeconomic foundation for technological knowledge growth and accumulation in firms by focusing on their intellectual property strategies across national boundaries. While the cumulative nature of scientific and technological knowledge has been recognized as central to economic growth (Grossman and Helpman, 1991; Romer, 1990) and pertinent to building organizational capabilities (Helfat, 1997; Helfat and Raubitschek, 2000), our understanding of the microeconomic foundation of cumulativeness is limited. The mere production of knowledge does not guarantee that others will be able to exploit it (Mokyr, 2002). Effective accumulation and use of knowledge require awareness of the extant knowledge and the ability to overcome the cost of accessing that knowledge. Recent studies have investigated the effects of research-enhancing organizations (Furman and Stern, 2011) and connectedness to external technical sources (Lim, 2009) on cumulativeness of knowledge. Nonetheless, prior work offers little guidance for understanding the roles of transnational IPRs in fostering knowledge formation and accumulation across countries with distinct IP institutional regimes. This study seeks to address this gap in the literature. It shows that patents awarded to firms under a weak IP institutional regime could influence the cumulativeness of knowledge of other firms under a strong IP institutional regime.

In the next section, we develop our conceptual framework and hypotheses. The ensuing section outlines the importance and suitability of using matched China and U.S. patent dyads as the empirical setting of this study. We then describe the data, measures and models. This is followed by the results and robustness analyses. Finally, we provide the discussion and limitations of the study and suggest potential areas for future research.

## HYPOTHESES

### The effect of patent grant under weak IPR institutions

An institution-based view which encompasses institutional conditions and transitions has emerged to enrich and shape strategic decisions within organizations (Colyvas and Powell, 2006; DiMaggio and Powell, 1983; North, 1990; Scott, 1987, 1995; Williamson, 1975, 1985). Formally, institutions are defined by economist Douglass North (1990, pp. 3) as ‘the humanly devised constraints that structure human interaction,’ and by sociologist W. Richard Scott (1995, pp. 33) as ‘regulative, normative, and cognitive structures and activities that provide stability and meaning to social behavior.’ North’s (1990) conceptualization of formal and informal institutions maps to Scott’s (1995) scheme of the three supportive pillars: regulative, normative, and cognitive. Our interest lies in regulative institutions and their related laws.

The protection of private property rights is one the most important aspects of regulative institutions (Acemoglu, Johnson, and Robinson, 2001; Besley and Ghatak, 2009; North, 1991). An examination of technical knowledge adoption and accumulation by firms under one IPR institution in response to market signals originating in another IPR institution contributes new insights to the institutional perspective of firm strategy making. In particular, transnational patenting by a focal firm under a weak IPR institution could serve as a signal of technology potential and market opportunity to mitigate information asymmetry and influence knowledge adoption and formation by other firms under a strong IPR institution.

Patents conform in principle to Spence’s (1973) original conceptualization of a signal – they are costly to obtain and, through the government certification process provide a mechanism by which the innovative activities can be qualified. By serving as a signal, patents provide information that is capable of altering an observer’s probability distribution of unobserved variables (Hsu and Zeidonis, 2008; Spence, 1973). Like other predictors of quality such as founder background (Burton, Sorensen, and Beckman, 2002; Eisenhardt and Schoonhaven, 1990) and third party affiliations to the entrepreneurial firm (Gulati and Higgins, 2003; Hsu, 2004), patents can be used by entrepreneurial firms to attract external resources by conferring intrinsic value due to property rights (Zott and Huy, 2007), and to increase investor estimates of start-up firm value through venture capitalist funding-rounds valuation (Hsu and Zeidonis, 2008).

There is increasing scholarly interest to understand and empirically test the critical roles played by patents in bridging the information gap with the resource providers to secure venture financing and commercialize unproven technologies in emerging economies such as China (e.g., Hu and Mathews, 2008). Our study focuses on how patents can mitigate the information asymmetry under such an economy and affect knowledge adoption in another.

When firms undertake the patenting procedure, they incur substantial costs in terms of the financial and human resources devoted to the application and examination process, and the amount of time taken. Depending on if reexamination and deposit of biological materials are required, the estimated direct monetary expenses (including attorney fees but excluding maintenance fees) for obtaining a typical SIPO invention patent is about CN¥46,000 or US$7,300, based on the figures from official government-appointed agency (China Patent Trademark Office, 2010). The cost to the firms is lower when securing patents for inventions of higher quality – in terms of *relative* technical merits or economic value of the technology. Higher quality inventions are generally more novel and useful than lower quality inventions and thus have greater likelihood of being awarded a patent within a shorter period of time (with less reexamination required). The time taken to obtain a patent is an opportunity cost that is particularly high for firms which place a premium on speed to market. Thus, while firms can apply and be granted patents for both higher and lower quality inventions, firms pay less on average to obtain a patent for a higher than a lower quality invention. This is in line with the signaling framework (Spence, 1973) which suggests that 'high-quality types' incur lower cost in sending a signal. Patent signaling is particularly salient in markets where IPR institutional condition is inadequate and uncertain (Gans *et al.*, 2008), and information asymmetry between the senders – focal firms operating in China – and receivers of the signal – other firms in the U.S. – is prevalent (e.g., Chan, Menkveld, and Yang, 2008).

By serving as a signal, patent awarded to a specific technology under the weak IPR institution of China mitigates information asymmetry relative to other technologies developed in China. For other firms in the U.S. monitoring and studying relevant prior technologies (from China), the China patent provides: (1) an assurance of technology potential for further research and commercial development; and (2) a certification of market opportunity as strategic bargaining chips for cross-licensing, litigations against IPR infringement or establishing IPR territories. In other words, such patent could serve as a positive signal of technology potential and market opportunity in China and induce other firms in the U.S. to accumulate and further develop the knowledge based on the focal innovation. Hence:

> *Hypothesis 1: The grant of a patent to an invention under a weak IPR institution (i.e., China) will increase its subsequent technological knowledge adoption under a strong IPR institution (i.e., U.S.).*

**The moderating role of organizational home base**

For the next hypothesis, we focus on how the level of information asymmetry between the senders and receivers of the signal can affect the *salience of the signal*. In particular, we investigate how pronounced the signaling effect of a patent grant is when the sender is home based in China versus home based in the U.S.

Firms in the U.S. (i.e., receivers of the signal) may have greater familiarity and better understanding of the technological products and characteristics of other U.S.-based MNCs (i.e., senders of the signal) conducting R&D in China, relative to other domestic China-based firms. Adopting an institutional approach, scholars have argued that firms develop their capabilities in relation to their particular environment and thus possess resources that align with the specific institutional characteristics of their home country (Kogut, 1993; Thomas and Waring, 1999; Zaheer and Zaheer, 1997). The home environment could shape the characteristics of the national firms as well as their competitive advantages (Porter, 1990).

It follows that less information asymmetry exists between firms in the U.S. and those U.S.-based MNCs in China, compared to other China-based firms. Firms in the U.S. are better able to assess the quality (whether good or bad) of U.S.-based MNCs in China, relative to other China-based firms. This information asymmetry could be further reduced if other firms in the U.S. have prior knowledge about these U.S.-based MNCs in China through past experience or dealings with them. Furthermore, as U.S.-based MNCs in China have more established reputation (as perceived by other firms in the U.S.) compared to China-based firms, they are seen to be more likely to improve and uphold their reputation in the technology market, relative to less well-known Chinese firms.

Thus, the signaling effect could be higher when a China-based firm obtains a patent in China compared to when a U.S.-based firm obtains one. It follows that the award of a SIPO patent to a China-based firm, relative to a U.S.-based firm, will have a greater positive effect on subsequent knowledge adoption by other firms in the U.S.

*Hypothesis 2: The effect of a patent grant under a weak IPR institution (i.e., China) on subsequent technological knowledge adoption under a strong IPR institution (i.e., U.S.) will be greater when the patent is awarded to a China-based firm compared to a U.S.-based firm.*

**The moderating role of technology sector**

The remaining hypotheses explore the other boundary conditions in patent signaling under the weak IPR institution of China. Specifically, we seek to shed light on the substantive versus strategic nature of the signal – in terms of the technology sector to which the invention belongs; and the lucidity of the signal – in terms of the *de facto* IPR institutional quality of the regions where R&D for the patented technology is conducted.

The *nature of the signal* could depend on the technology sector to which the patent has been awarded. Patents are critical for investment and product development particularly in the chemical, pharmaceutical and biotechnology sector (Cohen, Nelson, and Walsh, 2000; Levin *et al.*, 1987; Mansfield, 1986; Mansfield, Schwartz, and Wagner, 1981). Technologies in this sector can be classified as discrete and not complex (Cohen *et al.*, 2000). While pharmaceutical and biotechnology firms patent a majority of their inventions (Mansfield, 1986), their patents are fewer in number and greater in substantive and intrinsic value compared to, for example, the computing, semiconductor and information sector (von Graevenitz, Wagner, and Harhoff, 2011).[2] Specifically, there are very few patent-holding firms for each chemical and biopharmaceutical technology area from 1980 to 2003 (von Graevenitz *et al.*, 2011). Each patent in this technology sector can play a substantive role in product development, mitigation of the hazards of expropriation by competitors (Gans, Hsu, and Stern, 2002) and capturing of market share even under the weak IPR institution of China. Thus, the granting of a patent in this sector could serve as a positive signal to reduce information asymmetry and increase subsequent technological knowledge adoption by other firms in the U.S.

> *Hypothesis 3a: The effect of a patent grant under a weak IPR institution (i.e., China) on subsequent technological knowledge adoption under a strong IPR institution (i.e., U.S.) will be greater when the patent is awarded in the chemical and biotechnology sector.*

On the other hand, in the computing, semiconductor and information sector, patents are often used for strategic and defensive purposes. This sector is characterized by a diverse set of firms performing R&D on potentially overlapping and incremental technological products or processes. Firms often obtain patents in this sector in order to use them as cross-licensing bargaining chips, to establish their IPR territories, fend off litigation and mitigate potential

---

[2] For example, a rough comparison between the largest computer company and systems integrator, IBM and the largest pharmaceutical company, Pfizer shows that IBM has almost four times the number of granted patents (58,261) by USPTO alone until the end of 2008 compared to Pfizer (15,073). On the other hand, IBM and Pfizer have similar market capitalization in the fourth quarter of 2008 at U.S. $114.56 billion and U.S. $113.75 billion respectively.

hold-up problems in the markets for technology (Hall and Ziedonis, 2001; Ziedonis, 2004).

This sector has also experienced particularly strong growth and innovations over the last two decades in the emerging economy of China. With relatively more mature technological development and faster product life cycle, competition has become highly intense as more firms in this sector are amassing a large number of patents on their core technologies in order to strategically leverage them within and outside China (Hu and Jefferson, 2009). For example, many Taiwanese computer and integrated circuit manufacturers such as Elan Microelectronics and Taiwan Semiconductor Manufacturing Company (TSMC) have been aggressively patenting their core technologies in Taiwan and China to create strong patent portfolios. These are used as effective defense against U.S. firms like Agilent Technology and Avago Technology in patent infringement lawsuits and as bargaining chips when negotiating with these U.S. firms entering the Chinese market down the road (Tsai, 2010). It follows that the granting of China patents in this sector could serve as an important signal of strategic market potential to mitigate information asymmetry and influence subsequent technological knowledge take-up by other firms in the U.S. Thus:

*Hypothesis 3b: The effect of a patent grant under a weak IPR institution (i.e., China) on subsequent technological knowledge adoption under a strong IPR institution (i.e., U.S.) will be greater when the patent is awarded in the computing and information sector.*

**The moderating role of R&D location**

The *lucidity of the signal* afforded by the granting of a patent in China is a function of the *de facto* institutional quality in terms of IPR protection, enforcement and legal systems across different geographic regions. Such *de facto* IPR institutional quality may constitute another boundary condition. Even under the generally weak IPR institutional environment of China, the level of local (i.e., provincial) protection and enforcement of a patented technology varies when a firm researches and develops its technology in a particular location (Fan and Wang, 2004; Wang, Fan, and Zhu, 2007). For example, the *de facto* IPR institutional quality is higher in the more advanced coastal provinces such as Guangdong, Zhejiang and Shandong, and in the major Chinese municipalities such as Beijing, Shanghai and Tianjin. These regions have a more robust and transparent IPR enforcement and legal systems (Du, Lu, and Tao, 2008; World Bank, 2008). The IP courts there are also more responsive and effective in IPR dispute resolution and enforcement to protect the IP assets of foreign and domestic firms. Furthermore, the IP courts in the municipalities are more separated from and thus less influenced by local administrative systems which could present an obstacle to IPR protection.

On the other hand, in many of the less developed inland western provinces of China such as Guizhou, Qinghai, Shaanxi, and Yunnan, the *de facto* IPR institutional quality is lower (Fan, Gillan, and Yu, 2010). The IPR enforcement and legal systems in these regions are less transparent and more influenced by the local administrative systems which could present an obstacle to IPR protection and enforcement. It follows that there is a higher level of uncertainty in the IPR institutional conditions and greater information asymmetry between firms in the U.S. and firms conducting R&D on novel technologies in these regions (compared to firms in regions of higher IPR institutional quality and more certainty). As a result, firms in the U.S. are relatively less able to assess the technology potential and market opportunity of the inventions developed by firms in these Chinese regions, all else equal.

Following the same logic, the signaling effect of a patent grant could be higher when the patent is granted to technologies developed by firms in such regions of lower *de facto* IPR institutional quality and of less transparency in their IPR legal system, relative to those technologies developed by firms in regions of higher *de facto* IPR institutional quality and greater transparency. Thus, the granting of a patent to technology researched and developed by a firm in these regions provides a stronger signal to mitigate information asymmetry for the (receiving) firms in the U.S., all else equal. This will have a greater positive effect on subsequent adoption of the technology.

> *Hypothesis 4: The effect of a patent grant under a weak IPR institution (i.e., China) on subsequent technological knowledge adoption under a strong IPR institution (i.e., U.S.) will be greater when the patent is awarded to inventions developed by firms in regions of lower de facto IPR institutional quality*.

Taken together, the conceptual framework shown in Figure 1 delineates how under the weak IPR institutional environment of China where information asymmetry is high, the granting of a patent to the focal firm can serve as a signal of technology potential and market opportunity to induce subsequent knowledge adoption by other firms under the strong IPR institutional environment of the U.S. The boundary conditions are also shown in Figure 1.

-------------------------------
Insert Figure 1 about here
-------------------------------

## EMPIRICAL SETTING AND STRATEGY

### Empirical setting: China-U.S. patent dyads

After overtaking Germany and Japan, China has become the world's second largest economy in 2010 following the U.S. (International Monetary Fund, 2010). Despite its rapid scientific and technological advancement, rising GDP and household income, its IPR regime remains less than adequate (Zhao, 2006). However, there is a growing awareness and call for stronger IPR protection due to external pressure by foreign firms and organizations on the Chinese government and internal pressure from leading domestic technology firms such as Lenovo in computing, Huawei in telecommunications and Haier in consumer goods as they move up the value chain (Hu and Mathews, 2008; SIPO, 2010).

While the number of SIPO patents awarded to U.S. firms conducting R&D in China continues to climb rapidly (SIPO, 2008), there are also more incidents of patent infringement litigations by domestic Chinese firms against firms in major foreign markets such as the U.S. For example, domestic Chinese firms like Netacin – a pioneering Chinese firm in flash storage technologies – are starting to witness some successes in 2008 in defending their patents (on technologies originated and first patented in China) against incumbents like PNY in the U.S. Given the increasing emphasis on transnational patenting by firms in China and the U.S., China-U.S. patent dyads form a particularly interesting and important setting in our understanding of the impact of patent grant under a weak IPR institution like China on the technology's subsequent knowledge adoption under a strong IPR institution like the U.S.

To examine the impact of transnational patenting in the weak IPR institution of China on the technology's knowledge adoption in the strong IPR institution of the U.S., we construct and analyze a novel dataset of 4,226 China-U.S. patent dyads, covering 1,104 firms and organizations. A China-U.S. patent dyad encapsulates an invention whose patent had been first applied in China and subsequently applied and eventually granted in the U.S.[3] The sample includes the entire population of United States Patent and Trademark Office (USPTO) invention patents applied between 1985 to 2008 for which the same invention patent – known as a priority – had been first filed in China.

A priority right (or right of priority) is a time-limited right, triggered by the first filing of an application for a patent (i.e., origin of a technological invention). The priority right belongs to the applicant or her successor in title and allows her to file a subsequent patent application in another country for the *same invention*. The applicant can then benefit, for this subsequent application, from the date of filing of the first application for the examination of certain requirements by the appropriate patent office. When filing the subsequent application, the applicant must legally 'claim the priority' of the first application in order to make use of the right of priority. Thus, the priority right information in a patent can be used to precisely and effectively link a China patent with its U.S. counterpart to form a China-U.S. patent dyad. The period during which the priority right exists is usually 12 months for patents. The timeline illustrating the relationship of a typical China-U.S. patent dyad is shown in Figure 2.

------------------------------
Insert Figure 2 about here
------------------------------

The examination and final granting of a patent in each contracting country is independent of the others. While the Patent Cooperation Treaty (PCT) provides a unified procedure for the possibility of filing an international application (i.e., a PCT application) in each of its contracting countries, it does *not* provide for a 'multinational (or international) patent' (which does not exist). This is because the grant of patent is usually a prerogative of each national or regional authority (with few exceptions). In other words, the granting of a patent in each country is subject to the stringent patent examination procedure administered by individual countries. Each country has its own patent review and granting processes and varies to a different degree in assessing the patentability bar of novelty, usefulness and non-obviousness.

[3] The sample includes only patents eventually granted in the U.S. to control for the 'quality' of the invention and to mitigate underlying heterogeneity. This approach is consistent with previous literature (Jaffe, Trajtenberg, and Henderson, 1993; Murray and Stern, 2007).

For example, USPTO patent approval rate has dropped from about 72 percent in 2000 to 44 percent in 2008 (Wild, 2008) and SIPO has an average approval rate of about 44 percent for invention patents from 1985 to 2007 (SIPO, 2008). A firm may choose to patent in individual countries and not go through the PCT route in securing patents in another country.

Thus, due to the mandatory filing, examination and local enforcement of patents in each country, China-U.S. patent dyads provide a unique setting for us to exploit the differences in the timing of patent application and grant in China and in the U.S., and to shed light on our research questions.

**Empirical strategy**

To analyze the impact of the granting of a China patent to an invention on its follow-on technological knowledge adoption by other non-focal firms in the U.S., we rely on a number of methodological and econometric advances. First, we rely on forward citations (excluding firm self-citations) to the focal U.S. patent as a proxy for follow-on technological knowledge adoption by other firms (in the U.S.). Patent citations provide an inference on how subsequent firms and organizations have used and built upon the technological knowledge captured in the focal patent. As patent citations embody legal implications in property rights, firms and organizations, especially the non-focal ones, are conservative about which patents to cite. Usually only patented inventions upon which subsequent inventions directly build are being cited. Admittedly, citations are not perfect in measuring knowledge adoption. For example, they are often added for reasons such as avoiding litigation or clarifying claims, and many are in fact added by patent examiners rather than the inventors themselves. Despite this, scholars have shown that they correlate well with actual knowledge adoption and accumulation, especially when employing large samples (Duguet and MacGarvie, 2005; Jaffe and Trajtenberg, 2002). A concern could be the potential bias created by examiner-added citations (Alcacer and Gittelman, 2006). However, since inventors may have strategic motives for omitting certain citations, including examiner-added citations might actually be desirable (Lampe, 2012). While incorporating a robustness check using just inventor-added citations (i.e., non-examiner-added citations) is desirable, such data is not available for much of the time period of this study. Regression analysis based on the data with available examiner-added citations since 2001 suggest that using only inventor-added citations yields qualitatively similar results as using both inventor-added and examiner-added citations.

Second, we employ the difference-in-differences identification methodology (e.g., Murray and Stern, 2007; Rysman and Simcoe, 2008) to examine inter-firm technological knowledge adoption. To do this, we first calculate the inter-firm citations to the focal set of U.S. patents in the China-U.S. patent dyads, relative to the control set of U.S. patents *not* associated with a China patent. This identification approach compares the difference in the rate of knowledge adoption in the U.S. before and after the granting of the China patent based on the invention originated in China to other inventions from China, relative to the knowledge growth trajectory of 'similar' inventions *not originated in China*. The latter is captured by a control set of 4,226 'similar' patents with the same technology classes and application year but *not* originated in China. In fact, patented inventions in the control set predominantly (more than 92%) originated in the U.S. Each control patent is uniquely matched to a focal patent. As illustrated in Figure 3, this identification strategy exploits for each China-U.S. patent dyad: (1) the differences in the timing of patent application and grant respectively in China and U.S.; and (2) the *variation* in the timing of patent grant over a focal firm's invention in China as an *exogenous 'shock' to other non-focal (external) firms* in the U.S.[4] As such, this methodology provides a more precise estimate of: (1) the causal effect of patent grant in China after patents (on the same invention) have been applied in China and the U.S.; (2) the temporal effect of patent grant by observing changes in citation rates over time compared to conventional cross-sectional data approaches (Singh and Agrawal, 2011).

------------------------------
Insert Figure 3 about here
------------------------------

[4] In theory, only the first level of comparison is required for the difference-in-differences estimate (Murray and Stern, 2007; Huang and Murray, 2009) as it already provides the 'control set' which is forward citations in the patent-years before the China patent grant (of the focal USPTO patents associated with a China patent dyad). This is arguably a superior control to the sample of 'similar' USPTO patents that are never associated with a China patent dyad. However, including the control set of USPTO patents in the same technology classes and application year serves as an additional level of comparison with 'similar' inventions not originated in China.

## DATA, MEASURES AND MODELS

### Overview of data and sources

To analyze the impact of patent grant under the weak IPR institution of China on knowledge adoption under the strong IPR institution of the U.S., we develop a novel data set of 4,226 China-U.S. patent dyads, covering 1104 unique firms and organizations. This data set was constructed using the following procedure. As our focus is on technologies that are developed (or 'originated') in China and subsequently introduced to the U.S., we collected the entire population of granted USPTO invention patents with China priority until the end of 2008. Next, as a stringent criterion to ensure consistency in the country of originating patent application (which may affect the nature of patent filed), we include only patents that are first filed in China and subsequently in the U.S. – i.e., the SIPO patent application date must fall before (or on) the application date of its USPTO patent counterpart, matched using priority information.[5] This yielded 4,226 China-U.S. patent dyads where the U.S. patents had been applied and granted and the matching China patents had been applied and mostly granted.

To provide an additional layer of comparison of the rate of knowledge adoption with 'similar' technologies not originated in China, we construct a control set of 4,226 'similar' U.S. patents to the 4,226 focal U.S. patents in the China-U.S. patent dyads. Consistent with previous studies (Jaffe *et al.*, 1993; Singh and Agrawal, 2011), each control U.S. patent must be uniquely matched to a focal U.S. patent with the same three-digit technology classes and patent application year but must *not* be associated with a China priority patent.[6]

Based on the data set of 4,226 China-U.S. patent dyads and 4,226 control U.S. patents, we construct different variables to capture patent ownership and inventor characteristics, technology sectors, R&D location, as well as firm-level characteristics for each firm assigned a patent. Table 1 summarized the means, standard deviations, definitions and sources of these variables. Table 2 presents their correlations. Table 3 compares the descriptive statistics of

---

[5] Also consistent with previous studies (e.g., Hu and Mathews, 2008; Huang, 2010), we exclude patents from Hong Kong, Macau and Taiwan as these regions are not considered part of domestic China because of the intrinsic differences in their historical and technological developments, patent filing, and reporting systems.

[6] In fact, about 92 percent of the control U.S. patents (3,876 out of 4,226) claim technologies that originated in the U.S. based on priority information. Please also see construction and analyses of additional control sets 3 to 7 under the section on 'robustness analyses and additional control sets'.

the focal patents – U.S. patents each with a matching China patent dyad by priority – with that of the control patents – similar U.S. patents not associated with any China patent.

-----------------------------------------
Insert Tables 1, 2 and 3 about here
-----------------------------------------

We utilize the following major data sources to construct the data: (1) Data for the focal and control U.S. patents and citations are derived from the USPTO. (2) Data for the focal China patents and citations are obtained from the SIPO. (3) Data for the level of patent enforcement and dispute in each Chinese province are obtained from the SIPO Annual Reports (2000 to 2008). (4) Firm and organization characteristics are gathered from Compustat, USPTO and SIPO, supplemented by various industry publications, news articles and information on firm websites. These variables are then manually double checked and when in doubt, cross-referenced to company annual reports and news articles online. (5) The classification of strong and weak IPR countries, which remains reasonably stable over time, is based on the table of 'institutional environment and country classification' from Zhao (2006). It is compiled from eight key indices from general legal and political environment, IPR protection to rule of law and privacy, as shown in Table 4.

-----------------------------
Insert Table 4 about here
-----------------------------

**Constructing measures**

*Citation-year characteristics*

The dependent variable is *annual forward citation excluding firm self-citation*. It measures the yearly citations to a given U.S. patent excluding those made by the focal firm or organization awarded the U.S. patent.[7] It begins in the year the U.S. patent was applied for (earliest is 1985) and continues until 2008. This dependent variable captures follow-on knowledge adoption by *non-focal* firms and organizations. The total number of citation-year

[7] Two additional variations of the dependent variable, *annual forward citation excluding firm self-citation* are constructed. The first one, *annual forward citation* captures annual forward citations to the given U.S. patent made by follow-on patents from both focal and non-focal firms and organizations. The second one, *annual forward citation excluding inventor self-citation*, captures the annual forward citations to a given U.S. patent excluding citations made by any of the focal inventors listed on the U.S. patent. Using these two variations of dependent variable in the regression models yielded similar results.

observations is 66,268. By the end of the period, the average U.S. patent has accumulated over its lifetime close to 6 citations excluding focal organization self-citations as measured by the *total forward citation excluding firm self-citation* for each patent. The *U.S. patent* c*itation year* measures the calendar year in which a given citation is made.

*China patent characteristics*

The following variables are constructed to ascertain the temporal impact of a China patent grant and characteristics of the patent. The explanatory variable is *China patent in force* – a dummy variable equal to one for all years after the China patent is granted and zero prior to the patent grant. The mean of *China patent in force* is 0.26, suggesting that more than a quarter of the citation-year observation is distributed in the years when patents are in operation. *China grant year window* is another dummy variable which is coded one when the citation is received during the year the China patent is granted (i.e., the 'window') and zero otherwise. These two variables are derived from *China patent application year* and *China patent grant year*. We also construct *China patent grant lag* to denote the number of years between a China patent application and grant, and *China-U.S. patent lag* to denote the number of years between a U.S. patent application and its matching China patent dyad grant.

*U.S. patent characteristics*

The focal U.S. patents (of the China-U.S. patent dyads) and the control U.S. patents are characterized by the following variables. *Matching China patent dyad* (of the China-U.S. patent dyads) is a dummy variable set to 1 if the U.S. patent is associated with a matching China patent dyad. When this dummy variable equals zero, the U.S. patent is part of the control patent set. *U.S. patent in force* is a dummy variable equal to one for all years after the U.S. patent is granted and zero prior to the patent grant. *U.S. grant year window* is a dummy variable which is coded one when the citation is received during the year the U.S. patent is granted and zero otherwise. *U.S. patent application year* is the year in which the U.S. patent is filed. *U.S. patent grant year* is the year when the U.S. patent is awarded by the USPTO.

*Number of inventors* counts the number of inventors on the U.S. patent. *Number of* *classes* counts the number of national patent classes in the U.S. patent and provides a proxy for patent scope (Lerner, 1994; Scotchmer, 1991). *Number of claims* denotes the number of legal claims made by the U.S. patent and provides a proxy for patent strength (Harhoff and Reitzig, 2004; Lanjouw and Schankerman, 2001). *Number of patents in patent family* counts the number of unique patents contained in the international patent family of the U.S. patent. *Number of countries in patent family* counts the number of unique countries represented by the patents in the international patent family of the U.S. patent. Together, these two variables provide the international scope of the patent protection.

*Biochemical sector* is a dummy variable that denotes if the patent belongs to chemical, pharmaceutical or biotechnology related classes. *Computing and information sector* is a dummy variable that denotes if the patent belongs to computing or information storage related classes. *R&D location in weak IPR provinces* is a dummy variable that denotes if the patented technology is researched and developed in one of the eight Chinese provinces in the first quartile (lowest 25 percent) in IPR protection and enforcement: Qinghai, Inner Mongolia, Jilin, Shanxi, Hainan, Shaanxi, Yunnan, and Guizhou. Building on prior research (Fan *et al.*, 2010), we derived this measure from the average number of patent enforcement and dispute cases in the 31 Chinese regions at the provincial level between the years 2000 and 2008.[8]

*Firm and organization characteristics*

Using Compustat database, company annual reports, websites, and secondary data from various sources, we construct a series of variables to capture the firm- or organization-level characteristics for the 1,104 unique firms and organizations in the sample. First, we construct a series of dummy variables to ascertain the type of entity to which the patent is awarded. *Firm* denotes for-profit company or registered business entity. *University* denotes university, college or tertiary educational institution. *Research institute* denotes non-profit research institute, organization or national laboratory. *Hospital* denotes hospital, clinic or health care

[8] The data obtained from SIPO Annual Reports is available starting from year 2000. The eight provinces selected are among the lowest 25 percent in the level of IPR enforcement and protection. Analyses using alternative cut-offs for provinces in the lowest 20 or 30 percent yield similar results and consistent findings.

facilities. *Government* denotes central or state government agency, bureau, ministry, army, administration or council. *Individual* denotes individual owning the patent.

Second, to ascertain the home base of the firm or organization to which the patent is assigned, we construct the following variables. *Based in China* denotes if the assignee firm originates from or is home based in China. *Based in U.S.* denotes if the assignee firm originates from or is home based in the U.S.

Third, we construct *total assets* (mean = US$21.7 billion) and *total sales* (mean = US$32.3 billion) to denote the total cumulative assets (until the year of focal patent grant) and total sales (in the year of focal patent grant) for all publicly traded firms owning the focal patent respectively. The means reflect the large size and amount of assets of these firms. We also construct variables to proxy organizational research and innovative capabilities. *R&D spending* captures the total R&D expenditure of the (publicly traded) firm in the year of the focal patent grant. *Total number of patents* is the total number of patents of the organization which owns the focal patent over the organization's lifetime (i.e., to the end of 2008 when the sampling period ended). *Number of patents* denotes the cumulative number of patents of the organization which owns the focal patent until the end of the year of the focal patent grant. The high mean values of *R&D spending* (mean = US$0.93 billion), *total number of patents* (mean = 2,498) and *number of patents* (mean = 1,529) suggest that the firms and organizations in the sample are innovative with strong R&D capabilities and resources.

Finally, we construct variables to denote if the patented invention (of the focal firm) is developed in countries with weak IPR institutional regime like China or India or in countries with strong IPR institutional regime like the U.S. or Japan. Table 4 lists the strong versus weak IPR countries which remain reasonably stable over time (Zhao, 2006). *Developed China IPR weak* denotes if half or more of the U.S. patent inventors are based in China which indicates the invention is developed in China. *Developed U.S. IPR strong* denotes if half or more of the U.S. patent inventors are based in the U.S. *Developed non-U.S. IPR strong* denotes if half or more of the focal U.S. patent inventors are based in non-U.S., strong IPR countries such as U.K. or Japan. *Developed non-U.S. IPR weak* denotes if half or more of the focal U.S. patent inventors are based in non-U.S., weak IPR countries including China.

**Model specifications**

To more precisely ascertain the main effect of patent grant in China on technological knowledge adoption in the U.S., and the moderating roles of organizational home base, technology sector, and R&D location, we use the difference-in-differences identification approach (Furman and Stern, 2011; Rysman and Simcoe, 2008). This is achieved by comparing the difference in citations to focal U.S. patents – as the measure of technological knowledge adoption under a strong IPR institution – in the pre- versus post- China patent grant period for those citations affected by the patent grant to the same difference for unaffected citations, relative to citations to 'similar' control U.S. patents.

We use *annual forward citation excluding firm self-citation* to the U.S. patent by follow-on firms and organizations in the sample as the dependent variable. As this is a highly right-skewed count variable that takes on non-negative integer values, we use a nonlinear regression approach to avoid heteroskedastic, non-normal residuals (Hausman, Hall, and Griliches, 1984). There are two ways to deal with the discrete nature of such count data: the Poisson regression model (PRM) or the negative binomial regression model (NBRM), a generalized form of the Poisson regression (Hausman *et al.*, 1984). As Allison and Waterman (2002) point out that the conditional fixed-effects negative binomial model is not a true fixed-effects model since it fails to control for all of its predictors, we use fixed-effects Poisson model based on Wooldridge (1999). The fixed-effects Poisson estimator produces consistent estimates of the parameters in an unobserved components multiplicative panel data model under very general conditions and provides a consistent estimate of the conditional mean function even if the variances are misspecified (Wooldridge, 1999). As an additional verification, we employed fixed-effects negative binomial regression models with robust standard errors which yielded similar results. We also incorporate robust standard errors in the fixed-effects Poisson models (Simcoe, 2007) based on Wooldridge (1999), using the Huber-White sandwich estimator (Allison and Waterman, 2002; Greene, 2004) in all models to account for possible heteroscedasticity and lack of normality in the error terms.

In the difference-in-differences regression model given in Equation (1), the dependent variable is *annual forward citation excluding firm self-citation* which measures the extent of subsequent knowledge adoption of the focal technology. As we are interested in whether the granting of the China patent dyad affects subsequent knowledge adoption, we include the main explanatory variable, *China patent in force*, in the selection and marginal effects equation (1). We also include the variable *China grant year window* to account for the possibility that in the actual grant year of the China patent, the impact of IPR may be noisy. In addition, we control for other observable characteristics of the patents in equation (1):

$$\begin{aligned} FC_{i,t} = f\,(&\varepsilon_{i,t};\ \alpha China\_grant\_year\_window_{i,t} + \beta China\_patent\_in\_force_{i,t} \\ &+ \gamma matching\_China\_patent\_dyad_i + \delta number\_of\_inventors_i + \zeta firm_i + \eta university_i \\ &+ \lambda research\_institute_i + \mu hospital_i + \nu government_i + \xi number\_of\_classes_i \\ &+ \sigma number\_of\_claims_i + \rho number\_of\_patents\_in\_patent\_family_i \\ &+ \varsigma number\_of\_countries\_in\_patent\_family_i + \tau US\_grant\_year\_window_{i,t} \\ &+ \varphi US\_patent\_in\_force_{i,t}) \qquad (1) \end{aligned}$$

From equation (1), we develop the most stringent model to include both patent fixed effects and patent citation year fixed effects as shown in equation (2). The former controls for any underlying variations across each U.S. patent. The latter controls for any unobserved heterogeneity in each year when the forward citation is received by the patent.

$$\begin{aligned} FC_{i,t} = f\,(&\varepsilon_{i,t};\ \alpha China\_grant\_year\_window_{i,t} + \beta China\_patent\_in\_force_{i,t} \\ &+ \chi patent\ fixed\ effects_i + \psi citation\_year\ fixed\ effects_t) \qquad (2) \end{aligned}$$

In both equations, we can test whether the citation rate to the U.S. patent changes after the China patent dyad is granted, accounting for fixed differences in the citation rate across different patent dyads with different observable characteristics and over time. Using these two models to evaluate the effects of China patent grant, we then examine how organizational home base, technology sector and R&D location can respectively interact with China patent grant to affect subsequent technological knowledge adoption. This is given by equation (3):

$$FC_{i,t} = f\,(\varepsilon_{i,t};\ \alpha China\_grant\_year\_window_{i,t} + \beta China\_patent\_in\_force_{i,t}$$
$$+ \chi patent\ fixed\ effects_i + \psi citation\_year\ fixed\ effects_t$$
$$+ \pi patent\_firm\_base\_interactions_{i,t} + \gamma patent\_technology\_sector\_interactions_{i,t}$$
$$+\omega patent\_R\&D\_location\ \_interactions_{i,t}) \qquad (3)$$

## RESULTS

### Main effects of China patent grant

Models 5-1 to 5-4 in Table 5 investigate the baseline, selection, marginal and main effects of China patent grant on *annual forward citation excluding firm self-citation* of the U.S. patent dyads. We start with the ordinary least regression (OLS) model shown in Model 5-1, where the dependent variable is equal to the natural log of *annual forward citation excluding firm self-citation* plus one. While OLS provides a simpler interpretation of the result, it does not account for the skewed nature of the count data. The effect of the granting of China patent (*China patent in force*) is positive but not significant.

-----------------------------
Insert Table 5 about here
-----------------------------

This is followed by the Poisson model specifications described before, as shown in Models 5-2 to 5-4. For ease of interpretation, the coefficients are reported as incidence rate ratios (IRR) from Model 5-2 onwards.[9] Model 5-2 is the baseline model with controls for the number of inventors; whether the organization assigned the patent is a firm, university, research institute, hospital or government agency; the number of patent classes and claims; the number of unique patents and countries in the patent family; and U.S. grant year window and U.S. patent in force. Model 5-2 shows a positive and significant effect on knowledge adoption when the entity awarded the China patent is a hospital (67%), with increasing number of patent classes (4%) and claims (1%), and after the U.S. patent has been granted

[9] In Tables 5 and 6, we report the coefficients as incidence rate ratios (IRR) in all models except those in the OLS Model 5-1. IRR can be derived by exponentiating the coefficients, $\beta_k$ of the independent variable $x_k$ of the Poisson regression models. In this case, the IRR can be interpreted as the factor change in annual citations received in a given year due to a unit increase in the regressor. To illustrate, an IRR of 1.14 in the coefficient indicates a 14 percent increase in the dependent variable for a unit increase in the independent variable. An IRR of 0.49 indicates a 51 percent decrease in the dependent variable for a unit increase in the independent variable.

(275%). The effect is positive but not significant when the patent assignee is a firm (2%). On the other hand, there is a negative and significant impact when the patent assignee is a research institute (-31%) or government agency (-45%). The *number of patents in patent family* and the *number of countries in patent family* have no effects.

Model 5-3 is the selection and marginal effects model with controls. This model includes *China grant year window*, *China patent in force* and *China patent dyad* along with the same controls specified in Model 5-2, as well as patent citation year fixed effects. Model 5-3 provides a first test of hypothesis 1. The result shows that the granting of the China patent (*China patent in force*), by serving as a signal under the weak IPR institution of China, increases follow-on technological knowledge adoption under the strong IPR institution of the U.S. by about 17 percent (significant at 1%). The magnitude of the effects and significance of the control variables here are in line with those in Model 5-2. By including *Matching China patent dyad* in Model 5-3, it allows us to estimate the difference between U.S. patent associated with a granted China patent (i.e., technologies that originated in China) and U.S. patents not associated with a granted China patent, in terms of follow-on knowledge adoption. This selection effect suggests that U.S. patents associated with patented technologies from China (*China patent dyad*) are 51 percent less well cited cumulatively (significant at 1%) by other (non-focal) firms in the U.S. relative to U.S. patents not associated with China patent.

This finding is supported by the result from the most stringent specifications in Model 5-4 which includes *China grant year window*, *China patent in force*, patent fixed effects and patent citation year fixed effects. It suggests the granting of the China patent to a focal firm increases the follow-on citations to its U.S. patent dyad by other firms by about 11 percent (significant at 1%). Thus, Hypothesis 1 is supported.

Figure 4 displays the coefficients using the specifications in Model 5-4 for both the fixed-effects Poisson regression and the fixed-effects negative binomial regression. It shows the estimated temporal impact of China patent grant on follow-on citations for each year preceding and following the patent grant date. Patent grant in China has a positive and significant effect on follow-on citations in both models but the effect tapers off over time.

--------------------------------
Insert Figure 4 about here
--------------------------------

As a further validation, using the subsample of focal U.S. patents with matching China patent dyads, we estimate in Models 5-5 and 5-6 the impact of China patent grant based only on the difference in time lapsed between the application of the U.S. patent and the granting of its China patent dyad for each U.S. patent. This estimation excludes the control set of U.S. patents not associated with any China patent. Models 5-5 and 5-6 show the granting of the China patent dyad increases subsequent technological knowledge adoption in the U.S. by 26 percent and 76 percent respectively (both significant at 1%). This is consistent with the results from Models 5-3 and 5-4 and lends further support to Hypothesis 1.

**Salience of the signal: Moderating effects of organizational home base**

Using interaction variables, Models 6-1 to 6-3 in Table 6 shed light on the moderating effects of organizational home base under information asymmetry. Model 6-1 indicates that the signaling effect of China patent grant is more salient when the firm is based in China as shown by a 46 percent increase in forward citation rate (significant at 1%) compared to a non-significant 6 percent decrease when the firm is not based in China. Model 6-2 shows a 17 percent decrease (significant at 1%) in forward citation rate when the firm is based in U.S. versus a 19 percent increase (significant at 1%) when the firm is not based in U.S. The difference is statistically significant. Finally, Model 6-3 confirms the results from the previous two models and shows a 46 percent increase (significant at 1%) for China-based firms versus a 17 percent decrease (significant at 1%) for U.S.-based firms. The difference of 63 percent is statistically significant. Thus, Hypothesis 2 is supported.

------------------------------
Insert Table 6 about here
------------------------------

**Nature of the signal: Moderating effects of technology sector**

Models 6-4 investigates the impact when the patent is awarded in the biochemical sector as patents in this technology sector have substantive and intrinsic value and play an indispensable role in product development and revenue generation. In this model, we compare the interaction effects between *China patent in force* and *biochemical sector* with that of *China patent in force* and *non-biochemical sector*. Surprisingly, the interaction with *non-biochemical sector* yields a 15 percent increase (significant at 1%) compared to the non-significant interaction effect of *biochemical sector*. Hypothesis 3a is not supported.

Patents in the computing and information sector are often used for strategic and defensive purposes. In Model 6-5, we compared the interaction effects between *China patent in force* and *computing and information sector* with that of *China patent in force* and *non-computing and information sector*. Having a patent granted in the *computing and information sector* shows a 58 percent increase (significant at 10%) versus a modest 10 percent increase (significant at 1%) for *non-computing and information sector* interaction. The difference of 48 percent is statistically significant. Thus, Hypothesis 3b is supported.

**Lucidity of the signal: Moderating effects of R&D location**

Finally, Model 6-6 in Table 6 investigates the impact of China patent grant to an invention which is researched and developed in one of the eight Chinese provinces in the first quartile (lowest 25%) in IPR protection and enforcement. Here, we compare the interaction effects between *China patent in force* and *R&D location in weak IPR provinces* with that of *China patent in force* and *R&D location not in weak IPR provinces*. There is a 52 percent increase (significant at 10%) on follow-on knowledge adoption when the patent is granted to the invention researched and developed in a weak IPR province compared to a 10 percent increase (significant at 5%) when the invention is not researched and developed there. The difference of 42 percent is statistically significant. Thus, Hypothesis 4 is supported.

**Robustness analyses and additional control sets**

As a robustness check to verify the main results, we employ negative binomial regression models (with robust standard errors) which account for over-dispersion when the conditional variance is significantly greater than the conditional mean (Cameron and Trivedi, 1986, 1998). The negative binomial regression models yielded similar results to those of the

Poisson regression models (also see Figure 4). To test for citations by both focal and non-focal firms, and then by other non-focal inventors, we replaced the dependent variable, *annual forward citation excluding firm self-citation*, firstly with *annual forward citation* and then with *annual forward citation excluding inventor self-citation* in these models. The results are similar to that of the original models. Knowledge adoption is equally salient by focal and non-focal firms, and by non-focal inventors. To insulate the results against the possibility that the interaction effects in a non-linear model are not the same as their cross-partial derivatives (Ai and Norton, 2001), we performed additional regressions similar to Model 5-4 on split samples for Models 6-1 to 6-6 respectively. For example for Model 6-1, we performed regressions using data subsamples for *based in China* and *not based in China* separately. Results from these split sample analyses are consistent with the main findings.

To control for any unobserved heterogeneity across each firm, in Models 5-4 and 5-6 we substitute the most stringent patent fixed effects (which control for any unobserved heterogeneity across each U.S. patent) with *firm fixed effects* (which control for any potential underlying variation across each firm and organization). The results obtained are similar and consistent with the main findings. Another potential concern is that the increase in follow-on citations to focal U.S. patents after China patent dyad grant could be due to the natural increase in citations, which typically occurs in the first one to two years after U.S. patent grant. While the difference-in-differences estimation approach can already take into account of the effect of China patent grant on citations to U.S. patent for each year after the China patent grant for the entire sample (e.g., see Figure 4), we further assuage this concern by performing additional checks using Models 5-2 to 5-6 on the subsamples of patents in which China patent grant occurs two, three and four years *after* the *U.S. patent grant year* respectively when citations to a U.S. patent typically start to decline. These subsamples of patents all have citations to the U.S. patent dyad prior to China patent grant. The results remained strong and consistent with the main findings. Together, these provide robust support for the main results obtained using fixed-effects Poisson regression models.

To alleviate concern that the effects could arise due to a difference in technological origin (i.e., priority country) or subsequent patenting countries (i.e., patent family), we carefully constructed five more matching control sets to the focal China-U.S. patent dyads (set 1) and the original control set (set 2). These additional control sets (3 to 7) are respectively matched to sets 1 and 2 based on the same patent technology classes and application year. *Control set 3* contains 502 matching patents that have a non-U.S. strong IPR priority country and are subsequently patented in the U.S. These patents must have patent family from the same non-U.S. strong IPR country and the U.S. only. *Control set 4* contains 443 matching patents that have a non-China weak IPR priority country and are subsequently patented in the U.S. These patents must have patent family from the same non-China weak IPR country and the U.S. only. *Control set 5* contains 385 matching patents with the U.S. as the priority country, and patent family from the U.S. and a non-U.S. strong IPR country only. This suggests that the technology claimed in the patent originates in the U.S. but is later patented in a non-U.S. strong IPR country. *Control set 6* contains 270 matching patents with the U.S. as the priority country, and patent family from the U.S. and China only. This suggests that the technology claimed in the patent originates in the U.S. but is later patented in China. *Control set 7* contains 147 matching patents with the U.S. as the priority country and patent family from the U.S. and a non-China weak IPR country. This suggests that the technology claimed in the patent originates in the U.S. but is later patented in a non-China weak IPR country.[10]

First, we analyze the focal set with matching control sets 3 and 4 respectively using regression models similar to Models 5-2 to 5-4. Comparing results from sets 2 to 4, we find that the main effects of patent grant in China remain strong whether the priority country is the U.S. (set 2), a non-U.S. strong IPR country (set 3), or a non-China weak IPR country (set 4). Next, we analyze the focal set to the matching control sets 5 to 7 respectively. Control patents in sets 5 to 7 must have the U.S. as priority country. We find consistently strong effects of China patent grant (over technology originating in China), relative to technology originating

[10] The number of matching control patents differs from sets 3 to 7 because each set contains all possible patents that fulfill the criteria imposed on its construction. Loosening the criteria to obtain a higher number of control patents (especially for sets 6 and 7) yielded similar and consistent results in the regression models.

in the U.S. (i.e., with U.S. priority) whether or not it is later patented in a non-U.S. strong IPR country (set 5), China (set 6), or a non-China weak IPR country (set 7). The effect is also not due to the number of times a technology is later patented in different IPR countries.[11] Overall, the results of our study are robust to a number of alternate specifications and samples.

## DISCUSSION AND CONCLUSION

While the institution of property right regime in many emerging economies such as China remains far from adequate, R&D and patenting of innovative technologies by domestic start-ups or MNCs in these markets have become the cornerstone of their intellectual property strategy. These firms usually patent in another country of high market potential such as the U.S. later on and increasingly engage in transnational patenting across countries to better safeguard their innovations across multiple markets. Surprisingly, we know little about the dynamics and impact of the granting of a patent under a weak IPR institution on technological knowledge adoption under a strong IPR institution. Drawing on research from market signaling and intellectual property strategy, this study provides the first large-scale systematic evidence of the positive effects of patenting by a focal firm under the weak IPR institution of China on subsequent knowledge adoption by other firms under the strong IPR institution of the U.S. It demonstrates that under the weak IPR environment of China where information asymmetry is high, obtaining a patent could send a signal to positively shape subsequent knowledge adoption and formation under the strong IPR environment of the U.S. This finding is pertinent to policy makers and managers given that technological information conveyed by firms in an emerging market could be 'noisy' and difficult to verify.

The signaling effect is more salient for patents awarded to China-based firms than to U.S.-based firms conducting R&D in China due to the presence of a higher level of information asymmetry between the China-based firms and other firms in the U.S, all else equal. The signaling effect is largely restricted to the computing and information storage sector. In this sector, patents are often sought for defensive and strategic purposes which

[11] Detailed descriptive statistics and regression result for each matching control set is available upon request.

could suggest a greater role for signaling. There is no significant effect for the biochemical sector where there are fewer patents and each patent has distinct and substantive value. The signaling effect is more pronounced when the technology is developed in the less advanced (and predominantly western) inland Chinese provinces of Qinghai, Inner Mongolia, Jilin, Shanxi, Hainan, Shaanxi, Yunnan, and Guizhou, where the *de facto* IPR institutional quality is lower, IPR legal system is less transparent and information asymmetry is higher.

These findings have important public policy implications. They highlight the notion that policy decisions affecting the IPR institutional quality in a country (or a region) are intrinsically linked to the knowledge activities in another. As such, government policies aimed at enhancing IPR protection and enforcement in one geographic region or institutional environment can reduce information asymmetry and influence knowledge adoption in another. To the extent that such mechanism may create a positive and self-reinforcing feedback loop to encourage subsequent knowledge accumulation and innovation, it may benefit firms conducting R&D in emerging economies like China as they increasingly engage in the production of knowledge and ‘indigenous’ innovation despite its inadequate IPR regime.

These findings also have strategic and managerial implications for innovating and entrepreneurial firms that produce, integrate and assimilate technological knowledge across national and geographic boundaries. Cumulative knowledge is an important strategic asset that provides options for long-term exploration and expansion into new and uncertain external markets (Kogut and Zander, 1992). Managers and decision-makers should appreciate the role of transnational patenting as a critical part of their IP strategies. Patenting a technology in an emerging economy associated with a high level of information asymmetry can influence its adoption by other firms in more developed economies. Specifically, organizational home base, technology sector and R&D location can shape subsequent use and accumulation of knowledge and innovation in another market. These are important strategic choices that should be carefully evaluated by innovating firms in view of their expanding global reach and increasing complexity of R&D operations in the emerging markets.

**Limitations and future research**

While this study deepens our understanding of the impact of transnational patenting strategies under the weak IPR institution of China on knowledge adoption and formation by other firms under the strong IPR institution of the U.S., it has a number of limitations. One limitation is that the present study only focuses on technological knowledge encoded in patents and does not examine non-codified knowledge. To the extent that inventions kept as industrial secrets contribute little to the stock of codified knowledge that can be more readily transferred and built upon by other firms and organizations, patent citations represent a useful indicator of future technological knowledge adoption and use. Nevertheless, examining the effect of patenting under one IPR institution on the accumulation of non-codified knowledge under another is a potentially important area for future research.

Another limitation is that this study only examines the effect of patent grant in China on the technology's subsequent knowledge adoption in the U.S. using citations to USPTO patents. As citations to SIPO patents are not mandatory and therefore incomplete, understanding the flow and accumulation of technological knowledge *within* China is confronted by such methodological constraint. However, as our focus is on knowledge adoption by firms in the U.S., citations to USPTO patents function as an appropriate proxy. Nevertheless, future research could look into the conceptual and empirical differences between USPTO and SIPO patent citations such as the level of completeness and motivation behind SIPO citations, and how well they trace knowledge accumulation in China.

Furthermore, this study focuses only on two countries – U.S. and China. While these are the world's two largest economies with contrasting IPR institutions and represent considerable policy and managerial interests for different key stakeholders, future work could extend the analyses to more countries to gain a fuller understanding of the dynamics and impact of transnational patenting strategies on firms' knowledge processes in those countries.

Table 1. Means, standard deviations, and definitions of variables

| Variable | Mean | S.D. | Definition | Source |
|---|---|---|---|---|
| **Citation-Year Characteristics** | | | | |
| Annual forward citation excluding firm self-citation | 0.44 | 1.40 | Yearly forward citations: citations to a given U.S. patent except those made by the focal firm or organization awarded the U.S. patent | USPTO |
| Total forward citation excluding firm self-citation | 5.70 | 13.55 | Total number of forward citations (except those made by the focal firm or organization) accruing to a U.S. patent over its lifetime (1984 to 2008) | USPTO |
| U.S. patent citation year | 2003 | 4.37 | The year in which the forward citation is received by the U.S. patent | USPTO |
| **China Patent Characteristics** | | | | |
| China patent in force | 0.26 | 0.44 | Binary variable (1/0) set to 1 if citation is received in years after the China patent grant year | SIPO |
| China grant year window | 0.04 | 0.20 | Binary variable (1/0) set to 1 if citation is received in the year of the China patent grant | SIPO |
| China patent application year* | 2000 | 5.05 | The year in which the China patent application is made | SIPO |
| China patent grant year* | 2002 | 4.57 | The year in which the China patent is granted | SIPO |
| China patent grant lag* | 2.85 | 1.99 | Number of years between a China patent application and grant | SIPO |
| China-U.S. patent lag* | 1.61 | 2.64 | Number of years between a U.S. patent application and its matching China patent dyad grant | SIPO/ USPTO |
| **U.S. Patent Characteristics** (8452 U.S. patents, 4226 associated with matching China patent dyads) | | | | |
| Matching China patent dyad | 0.50 | 0.50 | Binary variable (1/0) set to 1 if the U.S. patent is associated with a matching China patent dyad | SIPO/ USPTO |
| U.S. patent in force | 0.58 | 0.49 | Binary variable (1/0) set to 1 if citation is received in years after the U.S. patent grant year | USPTO |
| U.S. grant year window | 0.12 | 0.32 | Binary variable (1/0) set to 1 if citation is received in the year of the U.S. patent grant | USPTO |
| U.S. patent application year | 2001 | 4.67 | The year in which the U.S. patent application is made | USPTO |
| U.S. patent grant year | 2004 | 4.94 | The year in which the U.S. patent is granted | USPTO |
| Number of inventors | 2.41 | 1.90 | Number of inventors appearing on the U.S. patent | USPTO |
| Number of classes | 4.32 | 3.38 | Number of national patent classes in the U.S. patent | USPTO |
| Number of claims | 14.73 | 11.99 | Number of claims made by the U.S. patent | USPTO |
| Number of patents in patent family | 8.89 | 29.36 | Number of unique patents contained in the patent family of the U.S. patent | USPTO |
| Number of countries in patent family | 3.77 | 3.58 | Number of unique countries represented by the patents in the patent family of the U.S. patent | USPTO |
| Biochemical sector | 0.14 | 0.34 | Binary variable (1/0) set to 1 if patent belongs to chemical, pharmaceutical or biotechnology related classes | USPTO |
| Computing and information sector | 0.02 | 0.14 | Binary variable (1/0) set to 1 if patent belongs to computing or information storage related classes | USPTO |
| R&D location in weak IPR provinces | 0.01 | 0.11 | Binary variable (1/0) set to 1 if R&D for the patented technology is conducted in a Chinese province in the first quartile (lowest 25%) in IPR protection and enforcement: Qinghai, Inner Mongolia, Jilin, Shanxi, Hainan, Shaanxi, Yunnan, and Guizhou | SIPO/ USPTO |

| | | | | |
|---|---|---|---|---|
| **Firm/ Organization Characteristics** | | | | |
| Firm | 0.75 | 0.43 | Binary variable (1/0) set to 1 if at least one of the entities to which the patent is awarded is a for-profit company or registered business entity | Compustat; Firm websites and various industry publications |
| University | 0.06 | 0.23 | Binary variable (1/0) set to 1 if at least one of the entities to which the patent is awarded is a university, college or tertiary educational institution | University websites and publications |
| Research Institute | 0.02 | 0.15 | Binary variable (1/0) set to 1 if at least one of the entities to which the patent is awarded is a non-profit research institute, organization or laboratory | Institute websites and publications |
| Hospital | 0.002 | 0.05 | Binary variable (1/0) set to 1 if at least one of the entities to which the patent is awarded is a hospital or clinic | Hospital websites and publications |
| Government | 0.01 | 0.10 | Binary variable (1/0) set to 1 if at least one of the entities to which the patent is awarded is a central or state government agency, bureau, ministry, army, administration or council | Government websites and publications |
| Individual | 0.18 | 0.39 | Binary variable (1/0) set to 1 if at least one of the entities to which the patent is awarded is an individual | Various websites (if applicable) |
| Based in China | 0.29 | 0.44 | Binary variable (1/0) set to 1 if the firm or organization to which the patent is assigned originates from/ is home based in China | SIPO/ USPTO |
| Based in U.S. | 0.37 | 0.48 | Binary variable (1/0) set to 1 if the firm or organization to which the patent is assigned originates from/is home based in the U.S. | SIPO/ USPTO |
| Total assets** | 21.7 | 27.1 | Total assets of the publicly traded firm owning the focal U.S. patent until the year of focal patent grant (in U.S. $ billions) | Compustat |
| Total sales** | 32.3 | 25.9 | Total sales of the publicly traded firm owning the focal U.S. patent in the year of focal patent grant (in U.S. $ billions) | Compustat |
| R&D spending** | 0.93 | 1.66 | Total R&D expenditure of the publicly traded firm owning the focal U.S. patent in the year of focal patent grant (in U.S. $ billions) | Compustat |
| Total number of patents* | 2498 | 7985 | Total number of patents of the firm/organization which owns the focal U.S. patent over its lifetime (to end of 2008) | USPTO |
| Number of patents* | 1529 | 6244 | Cumulative number of patents of the firm/ organization which owns the focal U.S. patent until the end of year of the focal patent grant | USPTO |
| Developed China IPR weak | 0.33 | 0.47 | Binary variable (1/0) set to 1 if half or more of the focal U.S. patent inventors are from China | USPTO |
| Developed U.S. IPR strong | 0.37 | 0.48 | Binary variable (1/0) set to 1 if half or more of the focal U.S. patent inventors are from the U.S. | USPTO |
| Developed non-U.S. IPR strong | 0.12 | 0.33 | Binary variable (1/0) set to 1 if half or more of the focal U.S. patent inventors are from non-U.S. countries with strong IPR regime | USPTO |
| Developed non-U.S. IPR weak | 0.50 | 0.50 | Binary variable (1/0) set to 1 if half or more of the focal U.S. patent inventors are from non-U.S. countries with weak IPR regime | USPTO |

* For the focal set of China-U.S. patent dyads. ** Information available for publicly traded firms only.

Table 2. Correlations of variables (employed in the regression models)

| | Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Annual forward citation excluding firm self-citation | 1.00 | | | | | | | | | |
| 2 | China grant year window | -0.03 | 1.00 | | | | | | | | |
| 3 | China patent in force | -0.04 | -0.12 | 1.00 | | | | | | | |
| 4 | U.S. grant year window | -0.01 | 0.01 | -0.02 | 1.00 | | | | | | |
| 5 | U.S. patent in force | 0.12 | -0.13 | 0.25 | -0.43 | 1.00 | | | | | |
| 6 | Matching China patent dyad | -0.11 | 0.21 | 0.59 | 0.02 | -0.01 | 1.00 | | | | |
| 7 | Number of inventors | -0.01 | 0.00 | 0.00 | 0.00 | -0.04 | 0.03 | 1.00 | | | |
| 8 | Firm | 0.00 | -0.01 | -0.22 | 0.05 | -0.13 | -0.20 | 0.15 | 1.00 | | |
| 9 | University | -0.01 | 0.02 | 0.10 | -0.01 | 0.00 | 0.15 | 0.21 | -0.25 | 1.00 | |
| 10 | Research institute | -0.01 | 0.03 | 0.11 | -0.01 | 0.02 | 0.13 | 0.23 | -0.07 | 0.01 | 1.00 |
| 11 | Hospital | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.02 | -0.04 | 0.01 | -0.01 |
| 12 | Government | -0.02 | -0.01 | -0.03 | 0.00 | 0.00 | -0.03 | 0.10 | -0.13 | 0.01 | 0.04 |
| 13 | Individual | 0.00 | 0.01 | 0.19 | -0.04 | 0.13 | 0.17 | -0.28 | -0.80 | -0.15 | -0.10 |
| 14 | Number of classes | 0.07 | -0.04 | -0.09 | -0.03 | 0.03 | -0.13 | 0.09 | 0.06 | 0.00 | 0.05 |
| 15 | Number of claims | 0.08 | -0.04 | -0.14 | 0.00 | -0.06 | -0.18 | 0.06 | 0.14 | -0.01 | 0.02 |
| 16 | Number of patents in patent family | 0.08 | -0.01 | -0.03 | -0.01 | 0.02 | -0.04 | 0.10 | 0.06 | 0.01 | -0.01 |
| 17 | Number of countries in patent family | 0.03 | -0.01 | 0.01 | -0.04 | 0.07 | 0.07 | 0.15 | 0.09 | 0.02 | -0.01 |
| 18 | Based in China | -0.08 | 0.12 | 0.41 | 0.01 | -0.04 | 0.57 | 0.12 | -0.26 | 0.29 | 0.21 |
| 19 | Based in U.S. | 0.10 | -0.14 | -0.37 | -0.04 | 0.06 | -0.59 | -0.02 | 0.15 | -0.11 | -0.11 |
| 20 | Biochemical sector | -0.04 | -0.02 | -0.05 | -0.03 | 0.04 | -0.02 | 0.22 | 0.01 | 0.17 | 0.07 |
| 21 | Computing and information sector | -0.01 | 0.00 | -0.02 | 0.01 | -0.03 | -0.02 | 0.00 | 0.05 | -0.02 | -0.02 |
| 22 | R&D location in weak IPR provinces | -0.01 | 0.01 | 0.10 | -0.01 | 0.02 | 0.12 | 0.01 | -0.10 | 0.11 | -0.02 |

| | | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Hospital | 1.00 | | | | | | | | | | |
| 12 | Government | -0.01 | 1.00 | | | | | | | | | |
| 13 | Individual | -0.02 | -0.05 | 1.00 | | | | | | | | |
| 14 | Number of classes | -0.01 | 0.00 | -0.07 | 1.00 | | | | | | | |
| 15 | Number of claims | -0.02 | -0.01 | -0.14 | 0.09 | 1.00 | | | | | | |
| 16 | Number of patents in patent family | 0.00 | 0.00 | -0.06 | 0.09 | 0.14 | 1.00 | | | | | |
| 17 | Number of countries in patent family | 0.02 | -0.01 | -0.09 | 0.13 | 0.11 | 0.41 | 1.00 | | | | |
| 18 | Based in China | 0.03 | -0.01 | 0.15 | -0.06 | -0.11 | -0.05 | -0.03 | 1.00 | | | |
| 19 | Based in U.S. | -0.01 | 0.00 | -0.12 | 0.13 | 0.24 | 0.08 | 0.06 | -0.49 | 1.00 | | |
| 20 | Biochemical sector | 0.08 | 0.13 | -0.12 | 0.18 | 0.04 | 0.07 | 0.27 | 0.03 | 0.06 | 1.00 | |
| 21 | Computing and information sector | -0.01 | -0.01 | -0.05 | 0.01 | 0.00 | -0.01 | -0.04 | -0.02 | -0.03 | -0.04 | 1.00 |
| 22 | R&D location in weak IPR provinces | -0.01 | 0.01 | 0.05 | -0.03 | -0.02 | -0.01 | 0.01 | 0.17 | -0.08 | 0.02 | -0.02 |

All correlation coefficients with a magnitude of 0.01 or greater are significant at the 0.01 level.

Table 3. Descriptive statistics of focal U.S. patents (patents each with a China patent dyad) versus control U.S. patents (patents *not* associated with China patent)

| | | **Focal U.S. Patents Set (U.S. Patents Each Matched to a China Patent Dyad)** | | **Control U.S. Patents Set (U.S. Patents *Not* Associated with China Patent)** | |
|---|---|---|---|---|---|
| **Variable** | **n** | **Mean** | **S.D.** | **Mean** | **S.D.** |
| Annual forward citation excluding firm self-citation | 33133 | 0.29 | 1.03 | 0.58 | 1.68 |
| Total forward citation excluding firm self-citation | 33133 | 3.93 | 10.13 | 7.47 | 16.07 |
| U.S. patent citation year | 33133 | 2003 | 4.37 | 2003 | 4.37 |
| U.S. patent application year | 4226 | 2001 | 4.68 | 2001 | 4.67 |
| U.S. patent grant year | 4226 | 2003 | 4.84 | 2003 | 5.04 |
| Number of inventors | 4226 | 2.41 | 1.99 | 2.41 | 1.81 |
| Number of classes | 4226 | 3.91 | 2.89 | 4.73 | 3.76 |
| Number of claims | 4226 | 12.45 | 8.32 | 17.01 | 14.41 |
| Number of patents in patent family | 4226 | 7.18 | 8.36 | 10.60 | 40.60 |
| Number of countries in patent family | 4226 | 3.91 | 3.10 | 3.63 | 3.99 |
| Biochemical sector | 4226 | 0.21 | 0.40 | 0.22 | 0.42 |
| Computing and information sector | 4226 | 0.07 | 0.25 | 0.08 | 0.27 |
| R&D location in weak IPR provinces | 4226 | 0.02 | 0.15 | 0.00 | 0.00 |

Table 4. List of strong and weak IPR countries (Adopted from Table 1, Zhao, 2006)

| **Strong IPR Countries** | **Weak IPR Countries** | |
|---|---|---|
| U.S.A. | Indonesia | Egypt |
| Ireland | Russia | Malaysia |
| Italy | Ukraine | Slovak Republic |
| Singapore | China | Greece |
| Canada | Pakistan | Poland |
| France | Peru | South Africa |
| Japan | India | Czech Republic |
| Australia | Venezuela | Portugal |
| Norway | Brazil | Hungary |
| Belgium | Mexico | Chile |
| Sweden | Romania | Taiwan |
| New Zealand | Turkey | Spain |
| U.K. | Thailand | Hong Kong |
| Germany | Bulgaria | Israel |
| Denmark | Philippines | Korea |
| Netherlands | Argentina | |
| Australia | | |

This list is compiled using eight indices and is *reasonably stable over time* (Zhao, 2006). Three from the general legal and political environment: The Law and Order index from the ICRG Risk Rating System (*ICRG* 1997), the O-Factor from the Pricewaterhouse Coopers Opacity Survey (*The Opacity Index* 2000), and the Property Protection index from the *Index of Economic Freedom* (1995). Three indices on IPR protection: the Rapp and Rozek (1990) index, the Ginarte and Park (1997) index, and United States Trade Representative's Special 301 Watch List from 1999. In addition, the Rule of Law index from Kaufmann *et al.* (1999, 2002) and the Piracy index from the annual BSA Global Software Piracy Study (BSA, 2000) prepared by the International Planning and Research Corporation are used. As these indices differ in their coverage of countries and time periods, weights are applied to obtain this reasonably stable list. For detailed construction and references, refer to Zhao (2006).

Table 5. Poisson models of the main effects of China patent grant

| | **OLS: *DV* = ln (annual forward citation excluding firm self-citation+1)** *Non-IRR* coefficients reported | **Poisson: *DV* = annual forward citation excluding firm self-citation** Coefficients reported as incidence rate ratios, IRR | | | | |
|---|---|---|---|---|---|---|
| | **[5-1] OLS with marginal effects** | **[5-2] Baseline with controls** | **[5-3] Selection and marginal effects with controls and patent citation year fixed effects** | **[5-4] Full model with all fixed effects** | **[5-5] Marginal effects *(For sub-sample of focal U.S. patents with matching China patent dyads)*** | **[5-6] Full model with all fixed effects *(For sub-sample of focal U.S. patents with matching China patent dyads)*** |
| *Independent Variables* | | | | | | |
| China grant year window | 0.03*** | | 1.14** | 1.08* | 1.10 | 1.23*** |
| | (0.01) | | (0.07) | (0.05) | (0.07) | (0.05) |
| China patent in force | 0.004 | | 1.17*** | 1.11*** | 1.26*** | 1.76*** |
| | (0.004) | | (0.05) | (0.04) | (0.05) | (0.04) |
| Matching China patent dyad | -0.10*** | | 0.49*** | | N/A | N/A |
| | (0.00) | | (0.02) | | | |
| *Control Variables* | | | | | | |
| Number of inventors | 0.00** | 0.99 | 1.00 | | 0.99 | |
| | (0.00) | (0.01) | (0.01) | | (0.01) | |
| Firm | 0.01** | 1.02 | 1.03 | | 1.04 | |
| | (0.00) | (0.03) | (0.03) | | (0.04) | |
| University | -0.01 | 0.93 | 1.07 | | 1.07 | |
| | (0.01) | (0.07) | (0.07) | | (0.10) | |
| Research institute | -0.04*** | 0.69*** | 0.82*** | | 0.78*** | |
| | (0.01) | (0.05) | (0.06) | | (0.06) | |
| Hospital | 0.09** | 1.67*** | 1.63*** | | 1.56* | |
| | (0.04) | (0.29) | (0.26) | | (0.36) | |
| Government | -0.10*** | 0.55*** | 0.50*** | | 0.85 | |
| | (0.01) | (0.07) | (0.06) | | (0.19) | |
| Number of classes | 0.005*** | 1.04*** | 1.03*** | | 1.04*** | |
| | (0.00) | (0.00) | (0.00) | | (0.01) | |
| Number of claims | 0.003*** | 1.01*** | 1.01*** | | 1.02*** | |
| | (0.00) | (0.00) | (0.00) | | (0.00) | |
| Number of patents in patent family | 0.00*** | 1.00*** | 1.00*** | | 1.01*** | |
| | (0.00) | (0.00) | (0.00) | | (0.00) | |
| Number of countries in patent family | 0.00*** | 1.00 | 1.00 | | 0.94*** | |
| | (0.00) | (0.00) | (0.00) | | (0.01) | |
| U.S. grant year window | 0.18*** | 2.67*** | 3.19*** | | 3.57*** | |
| | (0.01) | (0.11) | (0.13) | | (0.21) | |
| U.S. patent in force | 0.24*** | 3.75*** | 4.42*** | | 4.22*** | |
| | (0.00) | (0.13) | (0.15) | | (0.22) | |
| Patent fixed effects | | | | Yes | | Yes |
| Patent citation year fixed effects | Yes | | Yes | Yes | Yes | Yes |
| *Regression Statistics* | | | | | | |
| Log-likelihood | | -67457 | -60892 | -33008 | -21589 | -11760 |
| Wald chi-square (p) | 0.000 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 |
| Number of observations | 66268 | 66268 | 66268 | 66268 | 33133 | 33133 |

Robust standard errors in parentheses. *p≤0.10; **p≤0.05; ***p≤0.01

Table 6. Poisson models of the moderating effects of organizational base, technology sector and R&D location

| | Poisson: *DV* = annual forward citation excluding firm self-citation<br>Coefficients reported as incidence rate ratios, IRR | | | | | |
|---|---|---|---|---|---|---|
| | **[6-1] Based in China vs. not based in China** | **[6-2] Based in U.S. vs. not based in U.S.** | **[6-3] Based in China vs. Based in U.S.** | **[6-4] Biochemical sector vs. Non-biochemical sector interaction** | **[6-5] Computing and information sector vs. Non-computing and information sector interaction** | **[6-6] R&D location in weak IPR provinces vs. R&D location not in weak IPR provinces interaction** |
| ***Independent Variable and Interactions*** | | | | | | |
| **China grant year window** | **1.10 (0.07)** | **1.10** (0.05)** | **1.11** (0.04)** | **1.09* (0.05)** | **1.08* (0.05)** | **1.08* (0.05)** |
| **China patent in force x Based in China** | **1.46*** (0.13)** | | | | | |
| **China patent in force x Not based in China** | **0.94 (0.07)** | | | | | |
| **China patent in force x Based in U.S.** | | **0.83*** (0.07)** | | | | |
| **China patent in force x Not based in U.S.** | | **1.19*** (0.04)** | | | | |
| **China patent in force x Based in China** | | | **1.46*** (0.05)** | | | |
| **China patent in force x Based in U.S.** | | | **0.83*** (0.07)** | | | |
| **China patent in force x Biochemical sector** | | | | **0.89 (0.09)** | | |
| **China patent in force x Non-biochemical sector** | | | | **1.15*** (0.04)** | | |
| **China patent in force x Computing and information sector** | | | | | **1.58* (0.26)** | |
| **China patent in force x Non-computing and information sector** | | | | | **1.10*** (0.04)** | |
| **China patent in force x R&D location in weak IPR provinces** | | | | | | **1.52* (0.24)** |
| **China patent in force x R&D location not in weak IPR provinces** | | | | | | **1.10** (0.04)** |
| ***Control Variables*** | | | | | | |
| **Patent fixed effects** | Yes | Yes | Yes | Yes | Yes | Yes |
| **Patent citation year fixed effects** | Yes | Yes | Yes | Yes | Yes | Yes |
| ***Regression Statistics*** | | | | | | |
| **Log-likelihood** | -32984 | -32997 | -32981 | -33004 | -33007 | -33007 |
| **Wald chi-square(p)** | 0.00 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 |
| **Number of observations** | 66268 | 66268 | 66268 | 66268 | 66268 | 66268 |

Robust standard errors in parentheses. *p≤0.10; **p≤0.05; ***p≤0.01

Figure 1. Conceptual framework

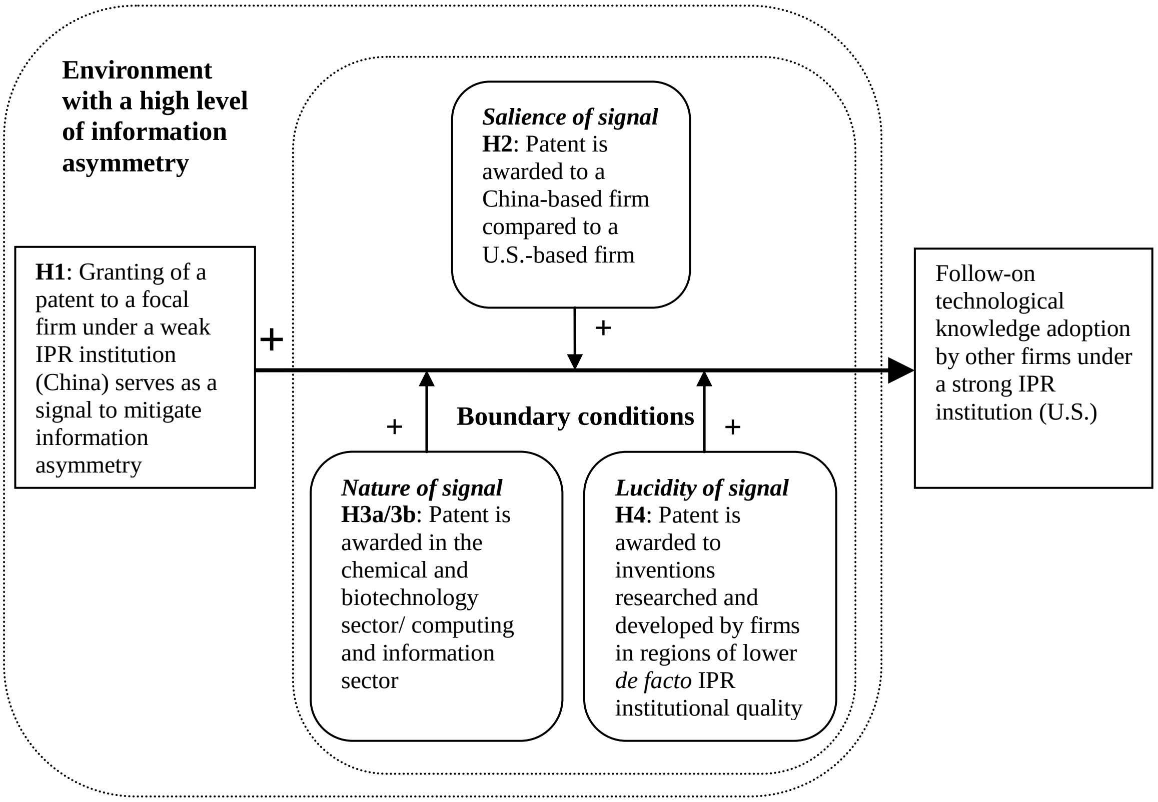



Figure 2. Timeline illustrating the relationship of a typical China-U.S. patent dyad and follow-on U.S. patent citations

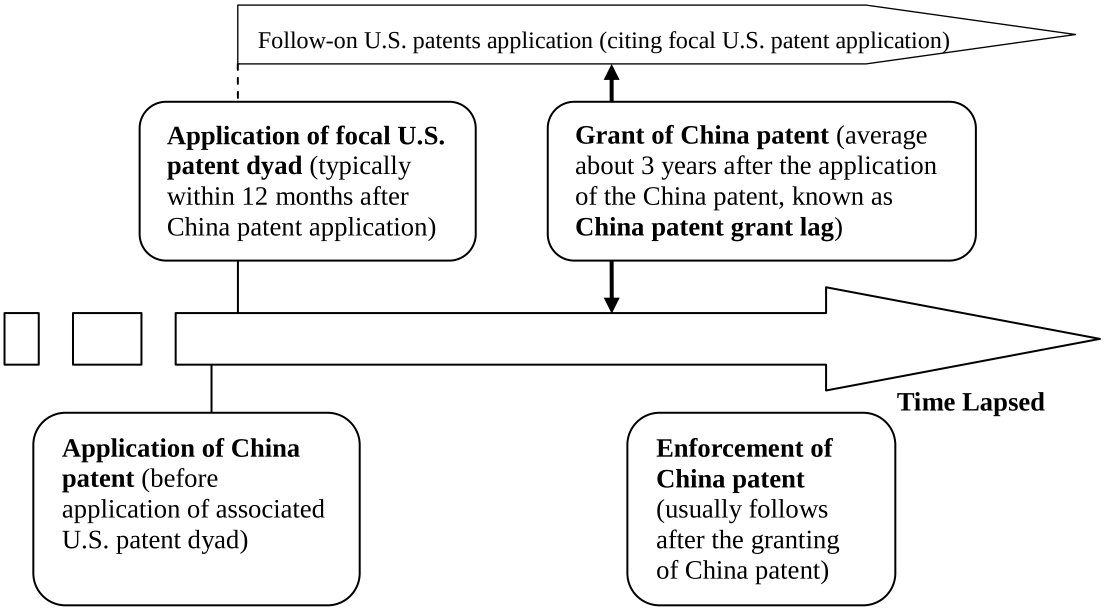


Figure 3. Empirical strategy: Difference-in-differences estimation

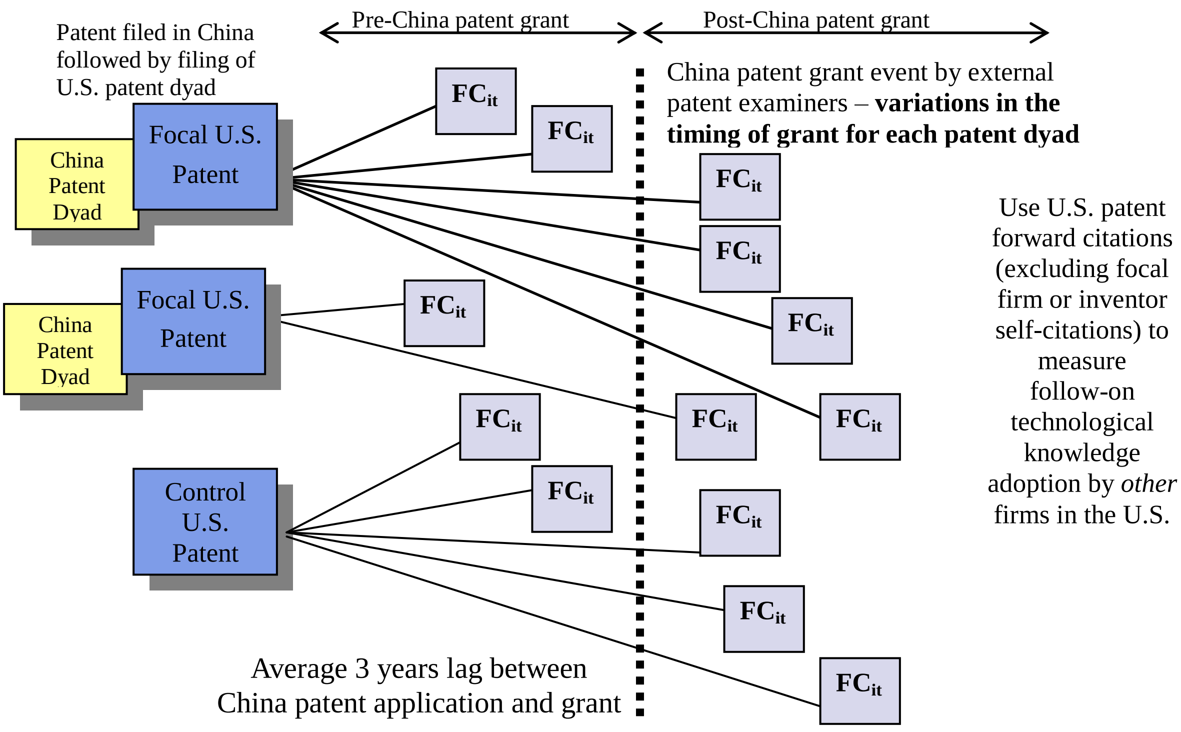
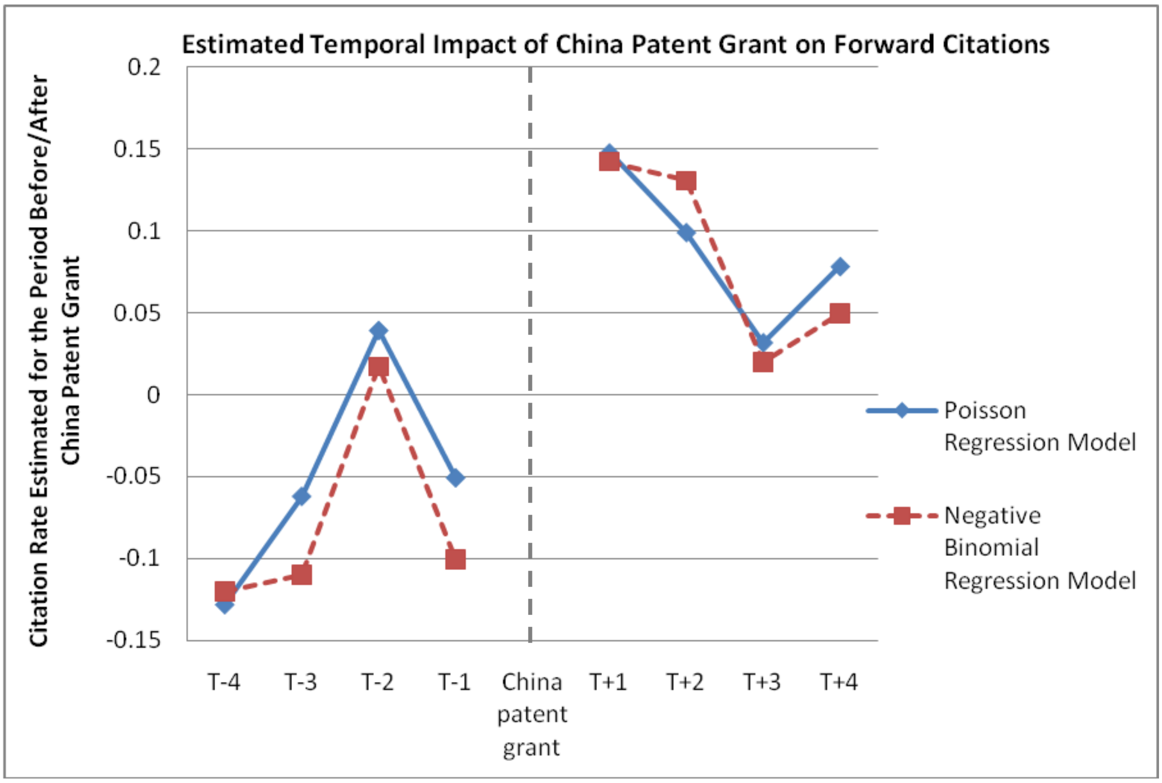



Figure 4. Estimated temporal impact of China patent grant on forward citations (Poisson vs. negative binomial regression models with patent fixed effects and patent citation year fixed effects)



## REFERENCES


Acemoglu D, Johnson S, Robinson JA. 2001. The colonial origins of comparative development: An empirical investigation. *American Economic Review* **91**: 1369-1401.

Ai C, Norton E. 2001. Interaction terms in nonlinear models. Working paper 2, Triangle Health Economics.

Alcacer J, Gittelman M. 2006. Patent citations as a measure of knowledge flows: the influence of examiner citations. *Review of Economics and Statistics* **88**(4): 774-779.

Allison PD, Waterman R. 2002. Fixed effects negative binomial regression models. R. Stolzenberg, Ed. *Sociological Methodology*. Basil Blackwell, Boston, MA.

Barrett C, van Biljon P, Musso C. 2011. R&D strategies in emerging economies. *McKinsey Quarterly* 1-9.

Besley T, Ghatak M. 2009. Property rights and economic development. In *Handbook of Development Economics*, Rodrik D, Rosenzweig MR (eds). North-Holland: Amsterdam, The Netherlands; 5.

Burton MD, Sorensen J, Beckman C. 2002. Coming from good stock: career histories and new venture formation. *Research in the Sociology of Organizations* **19**: 229-262.

Cameron CA, Trivedi PK. 1986. Econometric models based on count data: comparisons and applications of some estimators and tests. *Journal of Applied Econometric* **1**: 29-54.

Cameron CA, Trivedi PK. 1998. *Regression Analysis of Count Data.* Cambridge University Press: New York, NY.

Chan K, Menkveld AJ, Yang Z. 2008. Information asymmetry and asset prices: evidence from the China foreign share discount. *Journal of Finance* **63**(1): 159-196.

China Patent Trademark Office, 2010. Schedule of fees for Chinese patent. Accessed from http://www.chinatrademarkoffice.com

Cohen WM, Nelson RR, Walsh JP. 2000. Protecting their intellectual assets: appropriability conditions and why U.S. manufacturing firms patent (or not). NBER Working Paper 7552, National Bureau of Economic Research, Cambridge, MA.

Colyvas JA, Powell WW. 2006. Roads to institutionalization: The remaking of boundaries between public and private science. *Research in Organizational Behavior* **21**: 305-53.

Deeds D, Decarolis D, Coombs J. 1997. The impact of firm specific capabilities on the amount of capital raised in an initial public offering. *Journal of Business Venturing* **12**(1): 31-46.

DiMaggio PJ, Powell WW. 1983. The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. *American Sociological Review* **48**(2): 147–160.

Du J, Lu Y, Tao Z. 2008. Economic institutions and FDI location choice: evidence from U.S. manufacturing firms in China. *Journal of Comparative Economics* **36**: 412-429.

Duguet E, MacGarvie M. 2005. How well do patent citations measure knowledge spillovers? Evidence from French innovation surveys. *Economics of Innovation and New Technology* **14**(5): 375-393.

Eisenhardt KM, Schoonhoven CB. 1990. Organizational growth: linking founding team, strategy, environment, and growth among U.S. semiconductor ventures, 1978-1988. *Administrative Science Quarterly* **35**: 504-529.

Fan G, Wang XL. 2004. *The Report on the Relative Process of Marketization of Each Region in China.* Economic Science Press: Beijing, China.

Fan JPH, Gillan SL, Yu X. 2010. Innovation or imitation? The role of intellectual property rights protections. The Chinese University of Hong Kong Working Paper.

Furman J, Stern S. 2011. Climbing atop the shoulders of giants: the impact of institutions on cumulative research. *American Economic Review* **101**(5): 1933–1963.

Gans JS, Hsu DH, Stern S. 2002. When does start-up innovation spur the gale of creative destruction? *RAND Journal of Economics* **33**(4): 571-586.

Gans JS, Hsu DH, Stern S. 2008. The impact of uncertain intellectual property rights on the market for ideas: evidence from patent grant delays. *Management Science* **54**(5): 982-997.

Greene W. 2004. Fixed effects and the incidental parameters problem in the Tobit Model. *Econometric Review* **23**: 125-147.

Grossman G, Helpman E. 1991. *Innovation and Growth in the Global Economy*. MIT Press: Cambridge, MA.

Gulati R, Higgins M. 2003. Which ties matter when? The contingent effects of interorganizational partnerships on IPO success. *Strategic Management Journal* **24**: 127-144.

Hall BH, Ziedonis RH. 2001. The patent paradox revisited: an empirical study of patenting in the U.S. semiconductor industry, 1979-95. *RAND Journal of Economics* **32**(1): 101-128.

Harhoff D, Reitzig M. 2004. Determinants of opposition against EPO patent grants: the case of biotechnology and pharmaceuticals. *International Journal of Industrial Organization* **22**(4): 443-480.

Hausman JA, Hall BH, Griliches Z. 1984. Econometric models for count data with an application to the patents-R&D relationship. *Econometrica* **52**: 909-938.

Heeley MB, Matusik SF, Jain N. 2007. Innovation, appropriability and the underpricing of initial public offerings. *Academy of Management Journal* **50**: 209-225.

Helfat CE. 1997. Know-how and asset complementarity and dynamic capability accumulation: the case of R&D. *Strategic Management Journal* **18**(5): 339-360.

Helfat CE, Raubitschek RS. 2000. Product sequencing: co-evolution of knowledge, capabilities and products. *Strategic Management Journal*, October-November Special Issue **21**: 961-979.

Hu AG, Jefferson GH. 2009. A great wall of patents: what is behind China's recent patent explosion? *Journal of Development Economics* **90**(1): 57-68.

Hu M-C., Mathews JA. 2008. China's national innovative capacity. *Research Policy* **37**: 1465-1479.

Huang KG. 2010. China's innovation landscape. *Science* **329**(5992): 632-633.

Huang KG, Murray FE. 2009. Does patent strategy shape the long-run supply of public knowledge? Evidence from human genetics. *Academy of Management Journal* **52**(6): 1193-1221.

Hsu DH. 2004. What do entrepreneurs pay for venture capital affiliation? *Journal of Finance* **59**(4): 1805-1844.

Hsu DH, Ziedonis RH. 2008. Patents as quality signals for entrepreneurial ventures. *Academy of Management Best Paper Proceedings.*

International Monetary Fund (IMF). 2010. World economic outlook database: nominal GDP list of countries. October.

Jaffe AB, Trajtenberg M. 2002. *Patents, Citations and Innovations: A Window on the Knowledge Economy*. MIT Press: Cambridge, MA; Chapter 12.

Jaffe AB, Trajtenberg M, Henderson R. 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. *Quarterly Journal of Economics* **108**: 577-598.

Kogut B (ed). 1993. *Country Competitiveness: Technology and the Organizing of Work.* Oxford University Press: New York, NY and Oxford, UK.

Kogut B, Zander U. 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science* **3**(3): 383-397.

Lampe R. 2012. Strategic citation. *Review of Economics and Statistics* **94**(1): 320-333.

Lanjouw JO, Schankerman MA. 2001. Enforcing intellectual property rights. Discussion Paper 3093, Center for Economic and Policy Research, Washington, D.C.

Lerner J. 1994. The importance of patent scope: an empirical analysis. *RAND Journal of Economics* **25**(2): 319-333.

Levin R, Kievorick A, Nelson RR, Winter SG. 1987. Appropriating the returns from industrial R&D. *Brookings Papers on Economic Activity* 783-820.

Lim K. 2009. The many faces of absorptive capacity: spillovers of copper interconnect technology for semiconductor chips. *Industrial and Corporate Change* **18**(6): 1249-1284.

Lin Y. 2011. A practical patent strategy for foreign companies doing business in China. *Landslide Magazine of the American Bar Association Section of Intellectual Property Law*. January.

Mansfield E, Schwartz M, Wagner S. 1981. Imitation costs and patents: an empirical study. *Economic Journal* **91**: 907-918.

Mansfield E. 1986. Patents and innovation: an empirical study. *Management Science* **32**(2): 173-181.

Mokyr J. 2002. *The Gifts of Athena*. Princeton University Press: Princeton, NJ.

Murray F, Stern S. 2007. Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the anti-commons hypothesis. *Journal of Economic Behavior and Organization* **63**(4): 648-687.

North DC. 1990. *Institutions, Institutional Change, and Economic Performance.* Harvard University Press: Cambridge, MA.
North DC. 1991. Institutions. *Journal of Economic Perspectives* **5**: 97-112.
OECD. 2005. Patent database. Accessed from http://www.oecd.org/document/41/0,3746,en_2649_34451_40813225_1_1_1_1,00.html
Porter M. 1990. *The Competitive Advantage of Nations.* Macmillan: New York, NY.
Romer P. 1990. Endogenous technological change. *Journal of Political Economy* **98**: S71-S102.
Rysman M, Simcoe TS. 2008. Patents and the performance of voluntary standard setting organizations. *Management Science* **54**: 1920–1934.
Scotchmer S. 1991. Standing on the shoulders of giants: Cumulative research and the patent law. *Journal of Economic Perspectives* **5**: 29-41.
Scott WR. 1987. The adolescence of institutional theory. *Administrative Science Quarterly* **32**(4): 493–511.
Scott WR. 1995. *Institutions and Organizations.* Sage: Thousand Oaks, CA.
Simcoe T. 2007. XTPQML: Stata module to estimate fixed-effects Poisson (Quasi-ML) regression with robust standard errors.
Singh J, Agrawal A. 2011. Recruiting for ideas: how firms exploit the prior inventions of new hires. *Management Science* **57**(1): 129-150.
Sorenson O, Fleming L. 2004. Science and the diffusion of knowledge. *Research Policy* **33**: 1615-1634.
Spence M. 1973. Job market signaling. *Quarterly Journal of Economics* **87**: 355-374.
State Intellectual Property Office of China (SIPO). 2000. Patent law of the People's Republic of China (second amendment adopted on 25 August 2000), Article 20. Accessed from http://www.sipo.gov.cn/sipo_English/laws/lawsregulations/200804/t20080416_380327.html
State Intellectual Property Office of China (SIPO). 2008. Intellectual property rights statistical annual reports. Accessed from http://www.sipo.gov.cn/tjxx/
State Intellectual Property Office of China (SIPO). 2010. IP protection advances in China, China IP News, December 29. Accessed from http://english.sipo.gov.cn/news/ChinaIPNews/2010/
Stuart TE, Hoang H, Hybels R. 1999. Interorganizational endorsements and the performance of entrepreneurial ventures. *Administrative Science Quarterly* **44**: 315-349.
Thomas LG, Waring G. 1999. Competing capitalisms: Capital investment in American, German and Japanese firms. *Strategic Management Journal* **20**: 729-748.
Tsai B-H. 2010. Does litigation over the infringement of intellectual property rights hinder enterprise innovation? An empirical analysis of the Taiwan IC industry. *Issues and Studies* **46**(2): 173-203.
Von Graevenitz G, Wagner S, Harhoff D. 2011. How to measure patent thickets - A novel approach. *Economics Letters* **111**(1): 6-9.
Wang X, Fan G, Zhu H. 2007. China: Linking Markets for Growth. In Garnaut R, Song L, (eds). Asia Pacific Press: Canberra, Australia; chapter 3, 30-44.
Wild J. 2008. Patent quality and the plummeting USPTO approval rate. *Intellectual Asset Management Magazine.* March 6.
Williamson OE. 1975. *Markets and Hierarchies: Analysis and Antitrust Implications.* Free Press: New York, NY.
Williamson OE. 1985. *The Economic Institutions of Capitalism.* Free Press: New York, NY.
Wooldridge JM. 1999. Distribution-free estimation of some nonlinear panel data models. *Journal of Econometrics* **90**(1): 77-97.
World Bank. 2008. *Doing Business in China 2008*, Social Science Academic Press: Beijing, China.
Zaheer S, Zaheer A. 1997. Country effects on information seeking in global electronic networks. *Journal of International Business Studies* **28**(1): 77-100.
Zhao M. 2006. Conducting R&D in countries with weak intellectual property rights protection. *Management Science* **52**(8): 1185-1199.
Ziedonis RH. 2004. Don't fence me in: Fragmented markets for technology and the patent acquisition strategies of firms. *Management Science* **50**(6): 804-820.
Zott C, Huy QN. 2007. How entrepreneurs use symbolic management to acquire resources. *Administrative Science Quarterly* **52**(1): 70-105.